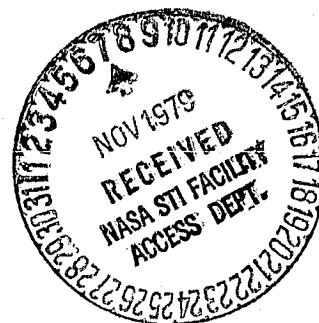


N O T I C E

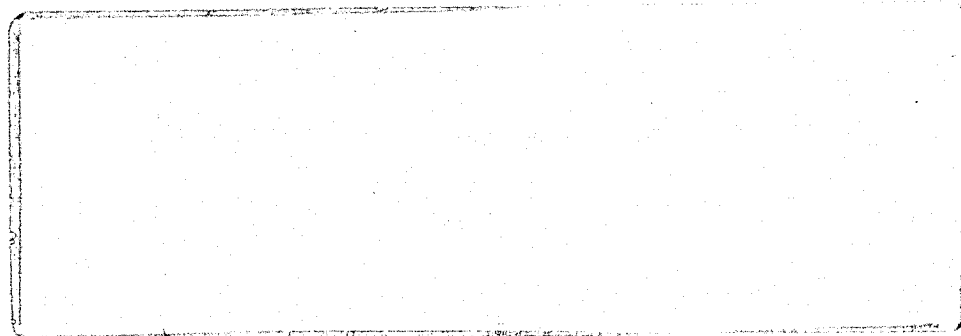
THIS DOCUMENT HAS BEEN REPRODUCED FROM
MICROFICHE. ALTHOUGH IT IS RECOGNIZED THAT
CERTAIN PORTIONS ARE ILLEGIBLE, IT IS BEING RELEASED
IN THE INTEREST OF MAKING AVAILABLE AS MUCH
INFORMATION AS POSSIBLE



(NASA-CR-161322) COAL CONVERSION PROCESSES
AND ANALYSIS METHODOLOGIES FOR SYNTHETIC
FUELS PRODUCTION Final Report (BDM Corp.,
McLean, Va.) 285 p HC A13/MF A01 CSCL 21D

N80-10379

Unclas
G3/28 45905





7915 Jones Branch Drive
McLean, Virginia 22102
Phone (703) 821-5000

October 5, 1979

BDM/W-79-548-TR

COAL CONVERSION PROCESSES AND ANALYSIS
METHODOLOGIES FOR SYNTHETIC FUELS PRODUCTION

Page intentionally left blank

THE BDM CORPORATION

FOREWORD

This final report is submitted to the George C. Marshall Space Flight Center, National Aeronautics and Space Administration, by The BDM Corporation, 7915 Jones Branch Drive, McLean, Virginia, 22102. This document summarizes the key findings of the study titled, "Coal Conversion Processes and Analysis Methodologies for Synthetic Fuels Production." This report was prepared under the guidance of Mr. Rodney Bradford at NASA-Marshall.

The report contains a description of modeling and analysis requirements to support evaluation of coal gasification plant designs; evaluation of models and methodologies available to satisfy the requirements; assessment of available coal gasification technologies; and an assessment of the Southeast regional market for coal gas.

This study was performed under Contract Number NAS8-33608. Questions of a technical nature should be addressed to either Mr. Dennis Warren, The BDM Corporation at (205) 881-3472 or Dr. Ronald M. Bass, The BDM Corporation at (703) 821-4262.

CONTRIBUTORS

THE BDM CORPORATION

Project Manager

Mr. Dennis Warren

Project Technical Staff:

Dr. Ronald M. Bass
Dr. Richard Dascher
Mr. W. D. Ditman
Mr. Joseph Dunkin
Ms. Judy Isreal
Ms. Nina Luce
Mr. James Query, Jr.
Dr. Joel M. Siegel
Dr. H. Austin Yingst

PROJECT CONSULTANTS

The Mittelhauser Corporation

Mr. W. T. Atkins
Mr. William Seward

Page intentionally left blank

THE BDM CORPORATION

TABLE OF CONTENTS

<u>Chapter</u>		<u>Page</u>
	FOREWORD	iii
	TABLE OF CONTENTS	v
	LIST OF FIGURES	xi
I	SUMMARY OF FINDINGS AND RECOMMENDATIONS	I-1 to I-21
	A. Introduction	I-1
	B. Requirements Analysis	I-1
	1. Overview	I-1
	2. Modeling and Analysis Requirements for Engineering Design	I-3
	3. Environmental Modeling Requirements	I-3
	4. Supporting Technology Department Development Requirements	I-4
	C. Modeling and Analysis Methodologies	I-6
	1. Purpose and Overview	I-6
	2. Steady State Flow Sheet Simulations	I-6
	a. Obtain Access to SSI-PROCESS, SYNTHA II and ASPEN	I-7
	b. Obtain Following Modifications to SSI-PROCESS	I-11
	3. Coal Gasification Reactor Models	I-11
	4. Economic Models and Methodologies	I-13
	D. Technology Base Status Assessment	I-15
II	REQUIREMENTS ANALYSIS	II-1 to II-41
	A. Purpose and Overview	II-1
	B. Requirements Analysis - Engineering Design and Analysis	II-2
	1. Gasification Plant Deployment Process and Schedule	II-2
	2. Conceptual Design and Analysis Process	II-5
	3. Modeling Requirements for Conceptual Design	II-7
	C. Requirements Analysis - Environmental Modeling and Analysis	II-8

THE BDM CORPORATION

Table of Contents (Continued)

<u>Chapter</u>	<u>Page</u>
1. Overview	II-8
2. Management of Environmental Aspects of Siting a New Commercial Coal Gasification Plant	II-10
a. Introduction	II-10
b. Management Program Background and Purpose	II-12
c. Phase I: Project Conceptualization	II-13
d. Phase II: Comprehensive Studies	II-17
1) Scaping and Initial Contacts	II-18
2) Regulatory Analysis	II-18
3) Impact Analysis Data Collection	II-19
4) Impact Analysis	II-20
5) Public Involvement	II-21
e. Phase III: Preparation of EIS	II-22
3. Environmental Modeling Requirements	II-23
D. Requirements Analysis - Supporting Technology Development	II-27
1. Introduction	II-27
2. Summary of Findings	II-27
3. Gasification Issues	II-29
a. Metallurgical Development	II-29
b. Scaled-up Issues	II-32
c. Chemical Processes	II-32
d. Automated Monitoring and Control	II-34
e. Slag and Coal Tar Removal	II-34
f. Char Removal	II-34
g. High Pressure Nozzels and Injectors	II-34
h. Catalysts	II-35
4. Pollution Control and By-product Utiliza- tion/Disposal	II-35
a. Identification of all Pollutants and Interactions	II-35
b. Utilization of Sulfur-By-Products	II-36
c. Particulates Entrapment	II-37
d. Slag Utilization	II-37

Table of Contents (Continued)

<u>Chapter</u>		<u>Page</u>
	5. Auxiliary Equipment Development	II-37
	a. Desulfurizers	II-37
	b. Oxygen Plant	II-38
	c. Water Purification	II-38
	d. Char Burning	II-39
	6. Utilization of Atmospheric Oxygen	II-39
	7. Transportation and Product Issues	II-39
	a. Alternative Transportation Options	II-39
	b. Product Storage	II-39
	8. Coal Preparation	II-40
	a. Development of New Techniques to Mini- mize Production of Fine-Sized Coal Particles	II-40
	b. Development of New Drying Techniques to Minimize the Amount of Energy Consumed in Coal Drying	II-40
	Attachment A - Federal Environmental Legislation Applicable to Coal Gasification	A-1
	Attachment B - Nature and Sources of Major Waste Streams Associated With the Gasification of Coal	B-1
III	MODELING AND ANALYSIS METHODOLOGIES	III-1 to III-44
	A. Purpose and Overview	III-1
	B. Steady State Flowsheet Simulation Systems	III-2
	1. Overview	III-2
	2. Overview of Steady State Process Flowsheet Simulation Systems	III-2
	3. Model Selection Criteria	III-9
	4. Available Steady State Flow Sheet Simula- tion Systems	III-11
	5. Recommendations for Steady State Flow Sheet Simulation	III-16
	a. Obtain Access to SSI-PROCESS, SYNTHA II and ASPEN	III-16
	b. Obtain the Following Modifications to SSI-PROCESS	III-16

Table of Contents (Continued)

<u>Chapter</u>	<u>Page</u>
C. Coal Gasification Reactor Models	III-19
1. Overview	III-19
2. Types of Coal Gasifier Reactors	III-19
3. Available Gasifier Models	III-21
a. Coal Gasification Simulator by Systems	III-23
b. Dynamically Modeled Coal Gasification Simulator	III-23
c. Fixed Bed Coal Gasification Simulator	III-23
4. Fluidized Bed Gasifier by H. S. Coram	III-23
5. General Gasifier Modeling by C. Y. Win	III-23
6. Modeling and Analysis of Moving Bed Coal Gasifiers	III-24
7. 1DICOG and PCGC-1 by F. P. Smith	III-24
8. NASA Combustion Materials	III-24
9. Findings and Recommendations	III-24
D. Detailed Approach and Findings - Economic Methods and Models	III-25
1. Introduction and Overview	III-25
2. NASA Requirements for Economic Models and Techniques	III-25
3. Available Models and Techniques	III-27
4. Criteria for Selection of Plant Cost Estimation Methods and Models	III-29
5. Findings and Recommendations	III-29
a. Summary of Findings and Recommendations	III-29
b. Background to Findings and Recommendations	III-32
c. Cost Estimation Models and Manual Techniques	III-33
d. Financial Models	III-36
6. Overview of the ESCOE Guidelines	III-36
a. Introduction	III-36
b. Collecting Necessary Inputs for Performance of Economic Evaluation	III-36
c. Cost Estimation	III-39

Table of Contents (Continued)

<u>Chapter</u>		<u>Page</u>
	7. Problems in the Economic Evaluation of Coal Conversion Processes	III-41
	a. Introduction	III-41
	b. Endogenous Uncertainty	III-44
	c. Methodological Problems	III-44
	d. Project Organization	III-44
	e. Exogenous Uncertainty	III-44
	Attachment A: Work Breakdown Structure for Cost Estimation and Financial Manual Evaluation	A-1 B-1
IV	TECHNOLOGY BASE ASSESSMENT	IV-1 to IV-17
	A. Introduction	IV-1
	B. Gasifier Processes Information Catalog	IV-2
	C. Technology Information and Status Assessment	IV-2
	D. Selection and Characterization of Candidate Processes	IV-9
	1. Feed Method	IV-10
	2. Coal Type	IV-10
	3. Product Gas Analysis	IV-10
	4. Process Pressure	IV-13
	5. By-Products	IV-13
	6. Oxidant Demand	IV-14
	7. Steam Demand	IV-14
	8. Gasifier Efficiency	IV-14
	9. Data Sources	IV-14
	E. Data Quality Evaluation	IV-14
	1. Overview	IV-14
	2. Economic Data	IV-17
V	POTENTIAL INDUSTRIAL MARKETS	V-1 to V-35
	A. Background and Purpose	V-1
	B. Summary of Findings	V-2
	1. National and Southeast Regional Markets	V-2
	2. Northern Alabama Markets	V-3

THE BDM CORPORATION

Table of Contents (Continued)

<u>Chapter</u>	<u>Page</u>
C. National and Southeast Regional Markets	V-3
1. Overview	V-3
2. National Industry Energy Uses	V-4
3. Southeast Region and Alabama Fossil Fuel Usage	V-12
4. Eastern Metropolitan Market Usage	V-12
5. National Uses of Coal Utilization Products Other Than Medium-BTU Gas	V-16
6. Cost and Economic Analysis	V-16
7. Medium-BTU Gas and Competing Fuel Prices	V-24
D. The North Alabam Market	V-28
1. Background and Prupose	V-28
a. Identify Major Current Industires in the North Alabam Regions and Their Energy and Product Requirements	V-30
b. Identify Industries Which Could be Attracted to Utilization of Synthetic Fuels Complex Processes	V-30
2. Summary of Findings	V-30
3. Detailed Approach and Findings	V-30
a. General	V-30
b. Consumption of Energy by Different Industries	V-31
c. Categarization of Industries by Potential Utilization of Coal-Based Synthetic Fuels	V-31
d. Large North Alabama Industries	V-32
e. Potential North Alabama Industrial Users of Coal-Based Synthetic Fuels	V-34
<u>Appendices</u>	<u>Page</u>
A CATALOG OF GOAL GASIFICATION SYSTEMS	A-1 to A-105
B CATALOG OF MODELS, ANALYTICAL METHODOLOGIES	B-1 to B-89

THE BDM CORPORATION

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
I-1	Organization of the Report	I-2
I-2	Modeling Requirements for Engineering Design	I-3
I-3	Categories of Environmental Models	I-4
I-4	Supporting Technology Development Issues	I-5
I-5	Models and Analysis Methodologies	I-6
I-6	Recommendations for Steady State Flowsheet Simulations	I-8
I-7	Additional Components Required in the SSI-PROCESS Data Base	I-9
I-8	Selection Criteria for Steady State Flowsheet Simulation System	I-10
I-9	Coal Gasifier Reactor Models	I-12
I-10	Criteria for Selection of Plant Cost Estimation Methods and Models	I-14
I-11	Features of Richardson Rapid System	I-16
I-12	Overview of ICARUS COST System for Plant Cost Estimation	I-17
I-13	Selection Criteria for Potentially Commercial Gasifiers in 1986-1990	I-18
I-14	Candidate Gasification Systems	I-20
I-15	Summary of Evaluation of Quality of Published Data for Seven Candidate Processes	I-21
II-1	Overview of Requirements Analysis	II-1
II-2	Coal Gasification Plant Preliminary Deployment Schedule	II-3/4
II-3	Conceptual Design Overview	II-6

LIST OF FIGURES (Continued)

<u>Figure</u>		<u>Page</u>
II-4	Modelling Requirements for Conceptual Design	II-9
II-5	Overview of Management Plan, Activities and Timing	II-15/16
II-6	Categories of Environmental Models	II-23
II-7	Schedule for use of Environmental Models	II-25/26
II-8	Supporting Technology Development Issues	II-28
III-1	Overview of Chapter III	III-1
III-2	A Process Flowsheet for a Shift Reactor in a Ny-gas SNA Plant	III-3/4
III-3	Steady State Flowsheet Model Inputs and Outputs for Chemical Processes	III-5
III-4	Typical Unit Operation Models in a Steady State Flowsheet Simulation	III-6
III-5	SYNTHA Flowsheet for a Combined Cycle Gasification Plant	III-8
III-6	Selection Criteria for Steady State Flowsheet Simulation System	III-10
III-7	Steady State Flowsheet Simulations	III-12
III-8	Recommendations for Steady State Flowsheet Simulations	III-17
III-9	Additional Components Required in the SSI-PROCESS Data Base	III-18
III-10	Nonproprietary Coal Gasifier Reactor Models	III-22
III-11	Requirements for Economic Analysis of a Coal-Based Synthetic Fuels Complex	III-26
III-12	Available Economic Models and Methodologies	III-28
III-13	Criteria for Selection of Plant Cost Estimation Methods and Models	III-31

THE BDM CORPORATION

LIST OF FIGURES (Continued)

<u>Figure</u>		<u>Page</u>
III-14	Findings and Recommendations	III-31
III-15	Features of Richardson Rapid System (Manual Cost Estimation)	III-34
III-16	Overview of ICARUS COST System for Plant Cost Estimation	III-35
III-17	Technical Development of Process Plants Classification of Project Stages	III-37
III-18	Classification of Cost Estimates	III-38
III-19	Capital Cost Summary	III-39
III-20	Rule-of-Thumb Process Contingencies	III-40
III-21	Summary of Annual Operating Costs	III-42
III-22	Financial Analysis - Data Summary	III-43
IV-1	Technology Status Assessment of Gasification	IV-5/6
IV-2	Candidate Gasification Systems	IV-12
IV-3	Technical Data Quality Evaluation	IV-15/16
IV-4	Summary of Evaluation of Quality of Published Data for Seven Candidate Processes	IV-18
V-1	Simplified Gasification Process	V-5
V-2	Gasifier Product Applications Matrix Composition of Gases as a Function of End Use	V-6
V-3	Industries Which Have High Potential for Synthetic Fuels	V-7
V-4	National End Uses of Purchased Fuel Energy	V-8
V-5	1974 National Industrial Energy Consumption by Fuel Type and End Use	V-9
V-6	Identification of Purchased Fuels and Electricity, 1974, National Manufacturing Industries	V-10

THE BDM CORPORATION

LIST OF FIGURES (Continued)

<u>Figure</u>		<u>Page</u>
V-7	Manufacturing Industries Electrical Energy Consumption (1976)	V-11
V-8	Purchased Fuels Other Than Electricity by State and Industry (10^{12} BTU/YR, 1976)	V-13
V-9	Comparison of the Five Metropolitan Markets Surveyed with Distance from North Alabama	V-14
V-10	Summary of Industrial Fuel Applications for Medium-BTU Gas	V-17
V-11	National End Uses of Elemental Sulfur	V-18
V-12	National End Uses of Sulfuric Acid	V-18
V-13	National End Uses of Carbon Dioxide	V-19
V-14	National End Uses of Fly Ash, Bottom Ash and Slag	V-19
V-15	Coal-Based Synthetic Fuels Cost/Price/Economics Variables	V-21
V-16	Coal Utilization Cost Analysis	V-23
V-17	Medium-BTU Gas Price as a Function of Capital Investment and Operating Cost	V-25
V-18	Costs for Medium-BTU Gasification Systems	V-26
V-19	Cost of Estimates of Various Coal Utilization Configuration vs. Conventional Industrial Fuel Prices	V-27
V-20	Northern Alabama Region	V-29
V-21	Large North Alabama Industries	V-33
V-22	Number of Facilities in North Alabama	V-35

THE BDM CORPORATION

CHAPTER I SUMMARY OF FINDINGS AND RECOMMENDATIONS

A. INTRODUCTION

The purpose of this study is (1) to provide information required to identify viable coal gasification and utilization technologies for the 1985-1990 time frame, (2) to identify analysis capabilities required to support design and implementation of coal-based synthetic fuels complex, and (3) to identify the potential market in the southeast United States for coal-based synthetic fuels.

This study was organized into four major tasks, listed as Chapters II-V in Figure I-1. A requirements analysis was performed to identify the types of modeling and analysis capabilities required to conduct and monitor coal gasification project designs. Based on these requirements, available models and methodologies to satisfy these requirements were identified and evaluated, and recommendations were developed. Requirements for development of technology and data needed to improve gasification feasibility and economies were also identified.

Separately, a technology assessment was conducted to identify processes that are potentially viable in 1985-1990. Finally, the southeast United States market for coal-based synthetic fuels was characterized. The report is organized as shown in Figure I-1 and is summarized in this chapter.

B. REQUIREMENTS ANALYSIS

1. Overview

The purpose of this task is to describe the analysis methodologies, modeling capabilities and supporting technology development required to conduct and monitor conceptual and detailed designs for coal gasification facilities.

THE BDM CORPORATION

CHAPTER II	REQUIREMENTS ANALYSIS
CHAPTER IV	MODELS AND ANALYSIS METHODOLOGIES
CHAPTER IV	TECHNOLOGY BASE STATUS ASSESSMENT
CHAPTER V	POTENTIAL INDUSTRIAL MARKETS
APPENDIX A	CATALOG OF GOAL GASIFICATION SYSTEMS
APPENDIX B	CATALOG OF MODELS AND ANALYTICAL METHODOLOGIES

Figure I-1. Organization of the Report

THE BDM CORPORATION

The requirements analysis is organized into three parts; requirements for engineering design, requirements for environmental management, and requirements for supporting technology development.

2. Modeling and Analysis Requirements For Engineering Design

The majority of the computation in engineering design is a steady state flowsheet analysis, which is almost universally conducted with computer simulation models. The balance of the computations, which represent a substantial effort, are most commonly performed manually, although financial evaluations (and costing to a much lesser extent) are performed with automated systems. Steady state process and utility flowsheet simulation is by far the most complex and extensive computer modeling analysis widely employed in conceptual design. Financial models are straightforward implementations of net present value computations. Additionally, some designers are turning to highly sophisticated automated systems to develop plant cost estimates.

Another potentially important class of models is gasifier models to predict gasifier yields. The gasifier is the primary type of process unit that cannot be modeled effectively with the kinds of unit operations models commonly provided in steady state flowsheet simulation packages. In the absence of effective gasifier models, the user would be required to specify the gasifier yields and duty as inputs to the flowsheet simulations.

- STEADY-STATE CHEMICAL PROCESS FLOWSHEET
- STEADY-STATE UTILITY ANALYSIS FLOWSHEET
- FINANCIAL EVALUATION
- PLANT COST ESTIMATING

Figure I-2. Modeling Requirements for Engineering Design

3. Environmental Modeling Requirements

There are no standards or protocols for the use of models in environmental impact assessment, and practices vary widely. There are,

THE BDM CORPORATION

however, a large number of models available to support the various impact analyses. The major categories of models applicable to coal gasification are listed in Figure I-3. As the focus of this study is engineering design, the environmental models are not discussed further in this report. The main purpose of the discussion of environmental management is to emphasize its heavy impact on engineering design and the need for close interaction between the two activities.

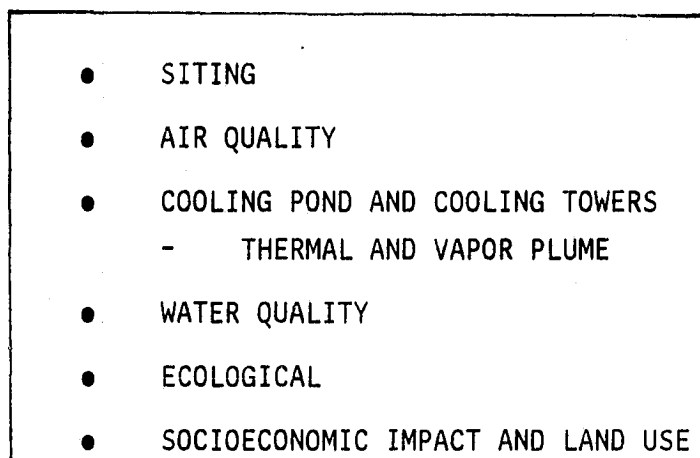
- 
- SITING
 - AIR QUALITY
 - COOLING POND AND COOLING TOWERS
- THERMAL AND VAPOR PLUME
 - WATER QUALITY
 - ECOLOGICAL
 - SOCIOECONOMIC IMPACT AND LAND USE

Figure I-3. Categories of Environmental Models

4. Supporting Technology Department Development Requirements

The principal results of the investigation into important technological areas in coal gasification are summarized below:

- (1) The results of our research indicate that an effective supporting technology development program is needed to identify areas of critical uncertainty in the coal conversion processes and address these uncertainties.
- (2) A study of the technology development issues associated with the development of a large scale, commercial synthetic fuels complex based on coal indicates that there are several areas where process improvements could significantly increase the economic viability of the project.
- (3) Figure I-4 provides an initial categorization of potential technology development issues related to the design development and

THE BDM CORPORATION

1. GASIFICATION ISSUES

- a. METALLURGICAL DEVELOPMENT OF GASIFICATION CHAMBER MATERIALS TO INHIBIT CORROSION/ERROSION
- b. RELIABLE SCALED-UP GASIFICATION CHAMBERS
- c. IMPROVED OVERALL UNDERSTANDING OF THE CHEMICAL ENVIRONMENT IN WHICH THE SCALED-UP, SPECIFIC GASIFICATION PROCESS OCCURS
- d. DEVELOPMENT OF AUTOMATED MONITORING AND CONTROL DEVICES TO INCREASE EFFICIENCY AND STANDARDIZE OUTPUT
- e. EFFICIENT REMOVAL OF SLAG AND COAL TARS TO PREVENT GASIFIER PLUGGING
- f. EFFICIENT REMOVAL OF VALUABLE CHAR DURING ON-GOING GASIFIER OPERATION
- g. DEVELOPMENT OF PRESSURIZED NOZZLES AND INJECTORS TO FEED A HIGH-PRESSURE, OPERATING GASIFIER
- h. DEVELOPMENT OF CATALYSTS WITH LONGER LIFE, HIGH GAS THROUGHPUT AND INCREASED SULFUR RESISTANCE

2. POLLUTION CONTROL AND BYPRODUCT UTILIZATION/DISPOSAL

- a. DEVELOPMENT OF A PROCESS-SPECIFIC DATA BASE CHARACTERIZING THE FULL RANGE OF POTENTIAL POLLUTANTS AND THEIR COMBINED EFFECT ON THE ENVIRONMENT
- b. UTILIZATION OF SULFUR BY-PRODUCTS
- c. AIRBORNE PARTICULATES ENTRAPMENT
- d. SLAG UTILIZATION/DISPOSAL

3. AUXILIARY EQUIPMENT DEVELOPMENT

- a. DEVELOPMENT OF LESS EXPENSIVE, MORE RELIABLE METHODS OF SOX SCRUBBING
- b. IMPROVED METHODS OF TREATING WATER POLLUTANTS RESULTING FROM GASIFICATION USING STEAM AND OXYGEN
- c. DEVELOPMENT OF IMPROVED METHODS OF BURNING BY-PRODUCT CHAR TO PRODUCE PROCESS POWER AND STEAM

4. UTILIZATION OF ATMOSPHERIC OXYGEN

5. TRANSPORTATION AND PRODUCT ISSUES

- a. SIMULATION OF ALTERNATIVE TRANSPORTATION OPTIONS
- b. PRODUCT STORAGE

6. COAL PREPARATION

- a. DEVELOPMENT OF NEW GRINDING TECHNIQUES TO MINIMIZE PRODUCTION OF FINE-SIZED COAL PARTICLES
- b. DEVELOPMENT OF NEW DRYING TECHNIQUES TO MINIMIZE ENERGY CONSUMED IN COAL DRYING

Figure I-4. Supporting Technology Development Issues

operating of a commercial scale synthetic fuels complex. A detailed discussion of each issue listed in this figure is given in this report. It is important to note that some of these issues must receive more intense technology development support than others. Therefore, it should be clearly understood that it is not our intent to imply that all of the issues in this list are of equal importance. However, each issue listed in this figure could, to varying degrees, increase the technical feasibility and commercial attractiveness of a synthetic fuels, coal-conversion complex if technological improvements were made with respect to that issue.

C. MODELING AND ANALYSIS METHODOLOGIES

1. Purpose and Overview

The purpose of this task is to identify, evaluate and recommend models and analysis methodologies that address the needs established in the requirements analysis. Based on those requirements, three categories of models and analysis methods were selected for investigation (Figure I-5); steady state flow sheet simulations, gasifier models, and economic models. Each of these categories is addressed below.

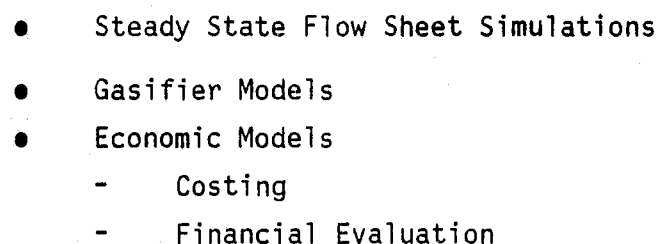
- 
- Steady State Flow Sheet Simulations
 - Gasifier Models
 - Economic Models
 - Costing
 - Financial Evaluation

Figure I-5. Models and Analysis Methodologies

2. Steady State Flow Sheet Simulations

The steady state flow sheet simulation system is a major computer modeling tool required to conduct reviews of A/E designs and to perform independent performance and economic tradeoff studies.

THE BDM CORPORATION

A steady state process flow sheet simulation system is used to construct models and simulate the characteristics of the physical streams flowing through a process plant under steady state operating conditions. BDM identified 37 steady state flow sheet simulation systems available from four sources; software vendors, private consulting firms, industrial firms and universities. A catalog describing each system is provided in Appendix A.

To obtain the full range of required steady flow sheet simulation capabilities, the following actions are recommended, as summarized in Figures I-6 and I-7.

a. Obtain Access to SSI-PROCESS, SYNTHA II and ASPEN

Based on the selection criteria listed in Figure I-8, BDM recommends that only systems provided through software vendors be considered, unless a required capability is available only through another source. Of the chemical process simulations available, the SSI PROCESS system satisfies all the selection criteria. Of particular note, SSI has conducted preliminary investigations and could implement additional needed capabilities (shown in Figure I-6) within a few months. SYNTHA II will satisfy requirements for utility simulation and will not require any modifications.

The ASPEN system, when completed, will address the need for both solids handling and chemical process simulation. ASPEN, however, will not be fully tested for a year or more. Use of ASPEN starting in October would provide experience with its unique solids handling and chemical process capabilities. At a later time, some of these capabilities can be incorporated into SSI-PROCESS or SYNTHA-II.

Access to SSI-PROCESS and SYNTHA-II can be obtained by subscribing to one of the time-sharing networks through which these systems are licensed. The networks will provide access to computer time, user manuals and training. Alternately the system may be leased directly from SYNTHA and SSI for operation on the user's own computers.

Access to the ASPEN system is arranged through the ASPEN project at MIT.

THE BDM CORPORATION

<u>RECOMMENDED ACTION</u>	<u>SATISFIES REQUIREMENT FOR</u>
I. OBTAIN ACCESS TO THE FOLLOWING MODELING SYSTEMS	
<ul style="list-style-type: none">● SSI-PROCESS● SYNTHA II● ASPEN*	<ul style="list-style-type: none">- CHEMICAL PROCESS SIMULATION- UTILITY SIMULATION- SOLIDS HANDLING AND CHEMICAL PROCESS SIMULATION
II. OBTAIN THE FOLLOWING MODIFICATIONS TO SSI-PROCESS:	
<ul style="list-style-type: none">● THREE PHASE FLASH WITH ELECTROLYTE DISSOCIATION	QUENCH AND OTHER SEPARATIONS
<ul style="list-style-type: none">● ADD COMPONENTS TO COMPONENT DATA BASE	REQUIRED FOR THREE PHASE FLASH (QUENCH) AND GAS CLEANUP MODELING
<ul style="list-style-type: none">● MULTICOMPONENT REACTION EQUILIBRIUM	SHIFT, METHANATION AND OTHER REACTIONS

*LIMITED NEAR-TERM AVAILABILITY

Figure I-6. Recommendations for Steady State Flowsheet Simulations

THE BDM CORPORATION

ELECTROLYTE COMPONENTS

*NH ₃	CRESOL
*CO ₂	XYLENOL
*H ₂ S	ACETIC ACID
*HCN	PROPIONIC ACID
*SO ₂	BUTYRIC ACID OTHER ORGANIC ACIDS
*PHENOL	METHANOL
*FORMIC ACID	ETHANOL
*HCL	ACETONE
*COS	ISOPROPANOL
*METHYL MERCAPTAN	NACL
ETHYL MERCAPTAN	KCL
CS ₂	THIOPHENE

ALKALI SALTS

*NaOH	K ₂ CO ₃
*Ca(OH) ₂	CaO
*Na ₂ CO ₃	NaSO ₃
PROPYLENE CARBONATE	

AMINES

MONOETHANOLAMINE	METHYL DIETHANOLAMINE
DIETHANOLAMINE	DI-ISOPROPOPANOL AMINE

*HIGHEST PRIORITY

Figure I-7. Additional Components Required in the SSI-PROCESS Data Base

THE BDM CORPORATION

- SIMULATES PROCESS STREAM CHARACTERISTICS AND UNIT OPERATIONS CONDITIONS FROM FLOWSHEET SPECIFICATIONS
 - CHEMICAL PROCESSES
 - UTILITIES
- ACTIVELY USED IN PROCESS INDUSTRY/UTILITY INDUSTRY
 - EXTENSIVE RELEVANT DATA BASE AND UNIT OPERATIONS MODELS
 - SHAKEN DOWN THOROUGHLY IN INDUSTRIAL DESIGN PROJECTS
- LARGE, ACTIVE USER COMMUNITY
 - FUNCTIONAL SOFTWARE
 - EFFECTIVE VENDOR SUPPORT
- ACCOMMODATES COAL-ORIENTED PROCESSES
- OPERATIONAL COAL SIMULATION SYSTEM AVAILABLE IN TIMELY MANNER

Figure I-8. Selection Criteria for Steady State Flowsheet Simulation System

THE BDM CORPORATION

b. Obtain the Following Modifications to SSI-PROCESS:

- (1) Add a unit operations model for a three phase flash with electrolyte disassociation in the water phase. The three phases are vapor, liquid hydrocarbon, and liquid water with electrolytes and organics. This model is required to model the quench and other separation units.
- (2) Add the components listed in Figure I-7 to the component data base. The electrolyte components are required for three phase flash calculations. The alkali salts are used in acid gas removal and SO_2 scrubbing. The amines are used as absorbents in hydrogen sulfide removal.
- (3) Add a capability to solve for multicomponent reaction equilibrium. This is required to solve for reaction products in methanation, shift and other reactions.
- (4) Add a math logic capability. This is the ability to compute any algebraic function of any stream properties or unit operation parameters; perform logical tests based on the computed quantity; and modify any stream property or unit operations parameter based on the outcome of the test. This capability increases user flexibility to address unusual situations.

3. Coal Gasification Reactor Models

Realistic gasifier models that accurately predict yields are a useful tool in integrating the gasifier into the overall design and planning for a coal gasification plant. The need to consider the fluid flows occurring in the gasifier, coupled with analyses of the thermodynamics and stoichiometry of the myriad of component substances and their interactions, contribute to the complexity of the problem of developing a useful gasifier model.

The available gasifier models that were investigated are listed in Figure I-9 and described in Appendix B. In no case has extensive validation been performed for any of these models on pilot or commercial scale reactors.

MODEL/DEVELOPER	TYPE OF GASIFIER	VALIDATED ON BENCH MODELS	VALIDATED ON PILOT OR COMMERCIAL SYSTEMS
1. COAL GASIFICATION SIMULATOR/ SSS	FLUIDIZED BED ENTRAINED FLOW'	NO	NO
2. DYNAMICALLY MODELLED COAL GASIFICATION SIMULATOR/ SCHEISSER	ENTRAINED FLOW	NO	NO
3. FIXED BED COAL GASIFICATION	FIXED BED	NO	YES
4. FLUIDIZED BED GASIFIER/ H.S. CARAVAN	FLUIDIZED BED	YES	NO
5. GASIFIER MODELLING/WIN	ALL	NO	NO
6. MODELLING AND ANALYSIS OF MOVING BED COAL GASIFIERS/ EPRI	MOVING BED	--	YES
7. IDI COG AND PCGC-1/P. SMITH	ENTRAINED FLOW	YES	NO
8. NASA COMBUSTION MODELS	ENTRAINED FLOW	--	YES ⁽¹⁾

(1) EXTENSIVE VALIDATION ON ROCKET ENGINES -- ONLY LIMITED VALIDATION ON GASIFIERS

Figure I-9. Coal Gasifier Reactor Models

THE BDM CORPORATION

Based on the study of available gasifier models, currently available non-proprietary models are too rudimentary to be of value as design tools. Specific findings are:

- (1) Models are usually one dimensional and most models do not have the ability to handle turbulent flow
- (2) Models are general, lacking necessary detail to model a real gasifier
- (3) Only two models have been even partially validated on a pilot or commercial plant
- (4) Investigators all report that results are very sensitive to the specified coal chemical composition, which is usually not well known in practice.

Based on these findings, the following recommendations are made:

- (1) Only validated models should be used
- (2) The models be used only for reasonability checks on vendor-specified yields, not as a design basis
4. Economic Models and Methodologies

The purpose of this task is to identify methods and models required for the economic analysis of a coal-based synthetic fuels complex. Economic methods and models have been selected to fulfill several potential needs, including evaluation of economic viability of specific coal conversion process plants, comparison of competing technologies, and the effects of market uncertainties and alternative financing arrangements for a specific project. Two analytic methods are required to fulfill these objectives; estimation of capital and operating costs of a process, and financial evaluation of the project.

BDM has surveyed available automated models and manual techniques for cost estimation and financial analysis. Criteria used to evaluate the usefulness of these models and techniques are listed in Figure I-10.

Guidelines for the economic evaluation of coal conversion processes prepared by ESCOE are recommended for use as a general guide to economic evaluation. They should be adhered to in all economic evaluations

THE BDM CORPORATION

- CONSISTENT WITH ESCOE GUIDELINES
- ACTIVE AND WIDESPREAD USE BY PROCESS DESIGN INDUSTRY
- ADEQUATE VENDOR SUPPORT
- APPLICABILITY TO ALL STAGES OF PROCESS DESIGN
- CURRENT DATA BASE

Figure I-10. Criteria for Selection of Plant Cost Estimation Methods and Models

THE BDM CORPORATION

to allow accurate comparisons of various technologies, and to serve as a framework for the appropriate use of various models and techniques for cost estimation and financial projections. For cost estimation, it was found that manual systems predominate in the process design industry. Two systems, commonly referred to as the Richardson Rapid System and the Guthrie Method, are widely acknowledged and utilized cost estimation techniques. The Richardson Rapid System (Figure I-11) is recommended for manual cost estimation. An automated cost estimation model, CØST, marketed by the ICARUS Corporation, is recommended for further examination (Figure I-12). CØST embodies a highly sophisticated methodology and an extensive up-to-date data base on equipment, material and labor costs by U.S. geographical location. It would provide a consistent and thorough costing of conceptual designs for approximately the same price as a manual costing, but in a few days rather than weeks or months. In using the effectiveness of both manual and automated methods depends upon the experience, knowledge and skill of the estimator.

Finally, it is recommended that the user develop a financial model in conformance with the ESCOE guidelines. Although there are several existing financial evaluation models, developing a new model will require only minimal effort and will ensure that the model exactly reflects the user's requirements.

D. TECHNOLOGY BASE STATUS ASSESSMENT

The purpose of this task was to investigate potential candidate coal gasification processes and to identify those which would most likely be ready for 1000 tpd or more commercial scale operation by a 1985-1990 time frame. Over 100 processes for production of low, medium, or high BTU gas were initially studied and cataloged (see Appendix A). Criteria were then established to narrow this large list down to processes that are operating on a reasonable scale today in pilot or commercial plants. For the twenty-two (22) processes remaining after this rough screening, evaluation

THE BDM CORPORATION

- EXTENSIVE CURRENT PRICE DATA BASE TO ESTIMATE PURCHASED EQUIPMENT COSTS GIVEN SIZE, FUNCTION, AND MATERIALS
- UTILIZES FACTORS TO ESTIMATE ADDITIONAL COSTS OF PIPING, WIRING, INSTRUMENTATION, INSULATION, AND PAINTING
- DATA BASE INCLUDES CURRENT PRICES BY LOCATION
- PROJECT CONTINGENCY APPLIED TO SUM OF ALL EQUIPMENT COSTS INCLUDING PURCHASE COST, INSTALLATION COSTS, AND DIRECT COSTS
- REQUIRES DETAILED CONCEPTUAL PLANT DESIGNS AND SCHEDULES

Figure I-11 Features of Richardson Rapid System
(Manual Cost Estimation)

THE BDM CORPORATION

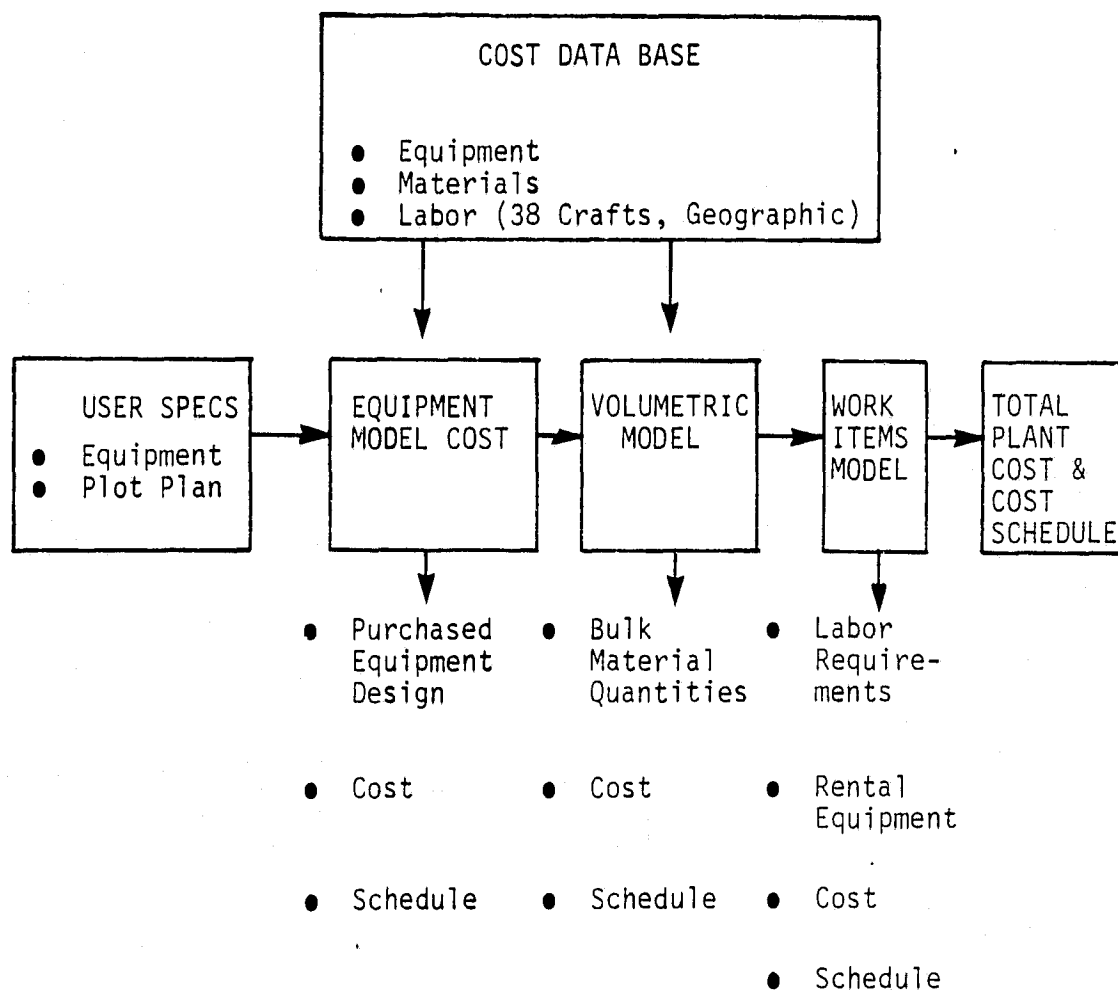


Figure I-12. Overview of ICARUS COST System for Plant Cost Estimation

THE BDM CORPORATION

- (1) MINIMUM OF A 100 TPD PILOT/DEMONSTRATION PLANT PRESENTLY IN OPERATION.
 - (A) THIS KEEPS SCALE-UP RISK TO THE 1000 TPD PLANT TO A REASONABLE LEVEL (10:1)
- (2) PILOT PLANT OR DEMONSTRATION PLANT RUNS OF A REASONABLE DURATION. THESE ARE NECESSARY TO VERIFY SUCCESS OF THE PILOT PLANT.
- (3) FUNDING: MUST HAVE AT LEAST PARTIAL FINANCIAL BACKING OF PARTIES SUCH AS HARDWARE OR PROCESSES MANUFACTURERS. PROCESSES FUNDED ENTIRELY BY PARTIES SUCH AS A-E's, UNIVERSITIES, FEDERAL GOVERNMENT, ARE NOT AS CREDIBLE AS DEVELOPERS OF COMMERCIALY VIABLE PROCESSES.
- (4) THE COMPLETENESS OF THE PILOT PLANT IS QUITE IMPORTANT. IDEALLY, ALL ELEMENTS NECESSARY FOR A FULL SCALE PLANT SHOULD BE IN THE PILOT; GASIFICATION SYSTEM, SOLIDS HANDLING SYSTEM, ACID GAS CLEAN-UP SYSTEM, ETC. ALSO, THE PLANT ELEMENTS IN THE SYSTEM SHOULD HAVE BEEN OPERATED IN A CLOSED CYCLE MODE TO WHATEVER EXTENT POSSIBLE.
- (5) THERE MUST BE CURRENT ONGOING DEVELOPMENT ACTIVITY. TO DESIGN AND BUILD A GASIFIER QUICKLY, THERE MUST BE A TEAM OF DESIGNERS CURRENTLY WORKING WITH THE TECHNOLOGY.

Figure I-13. Selection Criteria for Potentially Commerical Gasifiers in 1986-1990

THE BDM CORPORATION

criteria related to large scale commercialization potential for the process were applied to these. Based on the criteria listed in Figure I-13, seven were identified as processes that could possibly be implemented on a commercial scale (1000-2000 tons per day of coal per gasifier) by 1985-1990.

These processes are:

- (1) Dry Bottom Lurgi
- (2) Winkler
- (3) Koppers-Totzek
- (4) Texaco
- (5) Shell-Koppers.
- (6) Slagging Lurgi
- (7) Combustion Engineering

Each of those was then characterized (Figure I-14) as to product gas composition, byproducts, gasifier efficiency, type of coal used, and several other factors. Data on the economics of the individual processes were not included in this table. This was primarily due to the lack of uniformity in the data, as well as to the failure of any of the sources to adhere to the guidelines for such evaluations as set forth by ESCOE. (Described in Section E of Chapter III).

Also included is a section evaluating the quality of the data sources themselves to give an indication of the quality of data that is available in published reports. This analysis is summarized in Figure I-15.

The major conclusions to be drawn from evaluation of published technical data are that the conceptual design studies and process descriptions examined provide only limited information with which to evaluate the quality and validity of the designs. Of particular interest is the almost complete lack of documentation on the design data base, and pilot plant configuration and operation. As a result, the conclusions of the conceptual design studies cannot be critically evaluated from the published documents.

THE BDM CORPORATION

GASIFICATION	FEED METHOD	COAL TYPE	PRODUCT		BY-PRODUCTS LBS./TON COAL	OXIDAND DEMAND LBS./LB. COAL	STEAM DEMAND LBS./LB COAL	GASIFIER EFFICIENCY	DATA SOURCES	
			GAS ANALYSIS	PROCESS PRESSURE						
			Volume							
LURGI, DRY BOTTOM	OXYGEN BLOWN PRESSURE: #8 FIXED BED	PITTSBURGH 14,900 BTU/ LB. (ASH & MOISTURE FREE BASIS)	H ₂	39.4	350-450 PSIG	LIQ. HYDRO- CARBONS = 130 PHENOLS = 8	0.6 (O ₂)	3.2	63	(1),(2), (3),(11)
			CO	16.9						
			CH ₄	9.0						
			C _n H _m	0.8						
			H ₂ S+CO ₂	0.8						
			N ₂	1.6						
			CO ₂	31.5						
			285 BTU/SCF							
			65,000 SCF/TON COAL							
WINKLER	OXYGEN OR AIR BLOWN ATMOSPHERIC; FLUIDIZED BED	LIGNITE, 10,200 BTU/ LB. (DRY)	H ₂	35.3	ATMOSPHERIC	LIQ. HYDRO- CARBONS = NIL PHENOLS = NIL AMMONIA = NIL SULFUR = 20 ASH = 15-30% CARBON	0.5 (O ₂)	0.7	75	(1),(2)
			CO	48.2						
			CH ₄	1.8						
			C _n H _m	-						
			H ₂ S+CO ₂	-						
			H ₂	0.9						
			CO ₂	13.8						
			290 BTU/SCF (DRY)							
			62,000 SCF/TON COAL							
KOPPERS- TOTZEK	OXYGEN BLOWN ATMOSPHERIC; ENTRAINED BED	BITUMINUS 12,640 BTU/ LB. (DRY)	H ₂	36.0	ATMOSPHERIC	LIQ. HYDRO- CARBONS = NIL PHENOLS = NIL AMMONIA = NIL SULFUR = 20 ASH = CONTAINS 4% OF INPUT CARBON AS THE UNBURNED PRODUCT	0.9 (O ₂)	0.35	68-70	(1),(3), (4)
			CO	52.5						
			CH ₄	0.1						
			C _n H _m	-						
			H ₂ S+CO ₂	0.4						
			N ₂	1.1						
			CO ₂	10.0						
			286 BTU/SCF (DRY)							
			67,000 SCF/TON COAL							
BGC/SLAGGING LURGI	OXYGEN BLOWN PRESSURE, FIXED BED	SUB-BITUM. 13,000 BTU/ LB. (MOISURE + ASH FREE)	H ₂	28.1	300-350 PSIG.	LIQ. HYDRO- CARBONS = 600 PHENOLS = PRESENT BUT NO VALUES GIVEN AMMONIA = PRESENT BUT NO VALUES GIVEN	0.5 (O ₂)	0.28	68	(1),(2), (3)
			CO	61.2						
			CH ₄	7.7						
			C _n H _m	0.5						
			H ₂ S+CO ₂	-						
			N ₂	-						
			CO ₂	2.6						
			381 BTU/SCF							
			60,200 SCF/TON (MOISTURE & ASH-FREE BASIS)							
TEXACO	OXYGEN BLOWN PRESSURE ENTRAINED BED	ILLINOIS #6 13,150 BTU/ LB. (DRY)	H ₂	39.0	350 PSIG (RANGE, 350- 2500 PSIG FOR UNITS NOW UNDER DESIGN)	LIQ. HYDRO- CARBONS = NIL PHENOLS = NIL AMMONIA = NIL SULFUR - ASH CONTAINS <2% CARBON	0.8-0.9	NIL (FEED ENTERS AS A 50% WATER SLURRY)	66-73	(1),(2), (3),(5), (6),(7)
			CO	37.6						
			CH ₄	0.5						
			C _n H _m	-						
			H ₂ S+CO ₂	1.5						
			N ₂	0.6						
			CO ₂	20.8						
			253 BTU/SCF							
			53,000 SCF/TON COAL							
COMBUSTION ENGINEERING	AIR BLOWN ATMOSPHERIC ENTRAINED BED	PITTSBURGH/ KENTUCKY BITUM. BTU/ LB. - NO DATA	H ₂	10.6/17.0	ATMOSPHERIC	LIQ. HYDRO- CARBONS = NIL PHENALS = NIL AMMONIA = NIL ASH = LOW IN CARBON; CHAR FROM PRODUCT GAS IS RETURNED TO GASIFIER	4.5 (AIR)	NO STEAM NEEDED	~ 60	(1),(2) (9),(10)
			CO	24.7/22.1						
			CH ₄	0.0/0.0						
			C _n H _m	-						
			H ₂ S+CO ₂	0.5/0.6						
			N ₂	60.2/53.3						
			CO ₂	4.0/7.0						
			112/127 BTU/SCF							
			SCF/TON 130,000/150,000							
SHELL-KOPPERS	OXYGEN BLOWN PRESSURE ENTRAINED BED	BITUMINOUS, LOW ASH 11,800 BTU/ LB.	H ₂	28.0	400-470 PSIG	LIQ. HYD. = NIL PHENOLS = NIL AMMONIA = TRACE ASH = LOW IN CARBON, < 2% OF CARBON IS UNBURNED	0.7-0.9	NO DATA	74-77	(4),(8)
			CO	62.2						
			CH ₄	0.1						
			C _n H _m	-						
			H ₂ S+CO ₂	0.9						
			N ₂	3.5						
			CO ₂	2.4						
			316 BTU/SCF							
			SCF/TON	70,600						

Figure I-14. Candidate Gasification Systems

I. TECHNICAL DATA

- o LIMITED FLOW SHEET DATA
- o DESIGN DATA UNDOCUMENTED
- o LIMITED DOCUMENTATION OF PILOT OPERATIONS AND CONFIGURATION

CONCLUSION: CONCEPTUAL DESIGN STUDIES CANNOT BE CRITICALLY EVALUATED FROM PUBLISHED DATA

II. ECONOMIC ANALYSES

- o ONLY TWO STUDIES PRESENT METHODOLOGY AND CALCULATIONS
- o EXAMPLES OF OUTDATED ASSUMPTIONS AND DEFECTS IN METHODOLOGY*
 - NO ESCALATORS - 1976 DOLLARS
 - NO INVESTMENT TAX CREDIT
 - DO NOT USE NORMAL RED ACCOUNTING FOR DEPRECIATION (ACCELERATED DEPRECIATION PLUS RESERVE FOR DEFERRED TAXES)
 - NO STATE TAX
 - 10% COST OF CAPITAL (12% TODAY)
 - 50/50 DEBT/EQUITY RATIO (75/25 TODAY)
 - 52% FEDERAL CORPORATE TAX (46% TODAY)
 - CONSTRUCTION LOAN VALUED AT REGULATED RATE OF RETURN RATHER THAN COST OF CAPITAL

CONCLUSIONS: (1) MOST PUBLISHED ECONOMIC EVALUATIONS ARE NOT VALID FOR EITHER PROCESS COMPARISONS OR FEASIBILITY ANALYSIS

(2) DEFECTS IN METHODOLOGY CREATE HEAVY BIAS AGAINST CAPITAL INTENSIVE PROJECTS

* EPRI AI-642, JAN. 1978

Figure I-15. Summary of Evaluation of Quality of Published Data for Seven Candidate Processes

CHAPTER II
REQUIREMENTS ANALYSIS

A. PURPOSE AND OVERVIEW

The purpose of this chapter is to describe the analysis methodologies, modeling capabilities and supporting technology development required to conduct and monitor conceptual and detailed designs for coal conversion facilities. At NASA's request, this investigation was focused on coal gasification.

The requirements analysis is organized into three sections (Figure II-1); requirements for engineering design and development, requirements for environmental management, and requirements for supporting technology development. To establish the environmental and engineering modeling and analysis requirements, these two sections present the design and environmental management processes and identify the related modeling and analysis methodologies employed in these activities.

- REQUIREMENTS ANALYSIS - ENGINEERING DESIGN AND DEVELOPMENT
- REQUIREMENTS ANALYSIS - ENVIRONMENTAL MANAGEMENT
- REQUIREMENTS ANALYSIS - SUPPORTING TECHNOLOGY DEVELOPMENT

Figure II-1. Overview of Requirements Analysis

B. REQUIREMENTS ANALYSIS - ENGINEERING DESIGN AND ANALYSIS

1. Gasification Plant Deployment Process and Schedule

Overview of Gasification Plant Design and Development Process.

To provide a setting for discussion of the use of models in the plant design process and for design review, as well as the relation between the engineering and environmental tasks, the overall design and development process is described in this section. The major activities and a nominal schedule are illustrated in Figure II-2. As a first step, the project purpose and scope are defined, including plant products, size and other factors (Step 1.0). Environmental management is also initiated at this time, as described in detail in Section C of this chapter.

Next, the preliminary design basis is determined in Step 2.0. This data provides major inputs to the environmental management process and initial technology reviews. In the next step (Step 3.0), technologies are reviewed and characterized with regard to status, cost and environmental characteristics, and a few viable candidates are selected for detailed study.

Next, conceptual designs are developed (Step 4.0), including limited process simulations, market studies and cost estimates, and a process is selected for final design (complete conceptual design for the selected process).

If not done previously, the design coal is selected at this time (Step 5.0), considering availability and suitability to the process, and a contract is negotiated.

At this point, coal-specific tests are conducted (Step 6.0) to provide hard data for the final design. This includes characterization of all major and minor components, including analysis of very small concentrations of materials that can create processing problems.

Based on the test data and tradeoff studies conducted during conceptual design, the final design basis is now established in Step 7.0.

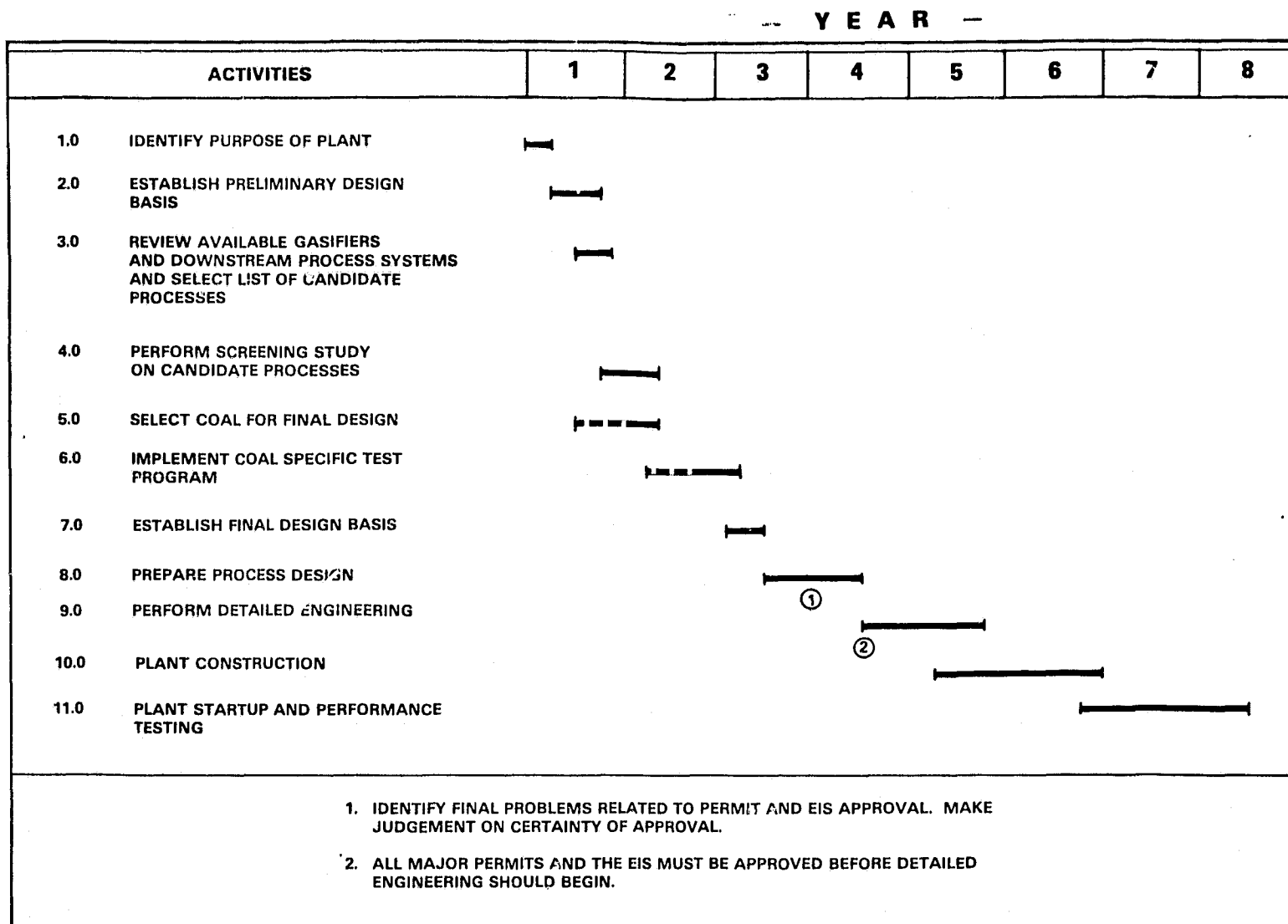


Figure II-2. Coal Gasification Plant Preliminary Deployment Schedule

THE BDM CORPORATION

The process design (Step 8.0) is then prepared from the final design basis. This step includes detailed simulations for tradeoff studies and final design preparation. Upon customer approval, this becomes the Final Design. Failure to conduct a thorough process design is an important cause of project delays and operating problems.

The project then moves into the detailed engineering phase (Step 9.0). This includes complete component and construction specifications.

Roughly half-way through detailed engineering, plant construction can get underway (Step 10.0). Finally, completion of construction, start-up and performance testing can begin (Step 11.0). After completion of satisfactory testing, the designer/constructor is released and the plant enters commercial operation.

During commercial operation, it is common practice to maintain plant simulations, which are used for operations planning and as a basis for continuing plant improvements.

2. Conceptual Design and Analysis Process

NASA's modeling requirements for monitoring of A/E design are the same modeling capabilities required for the conceptual design process, which are described in this section to illustrate the role of modeling in conceptual design. A simplified overview of the conceptual design process is illustrated in Figure II-3. A detailed description of cost data development and economic evaluations are provided in Section D of this chapter, and the steady state flow analysis is described in Section C of this chapter. BDM's recommended process for A/E design review is described in the next section.

First, project scope is defined. This includes capacity, operating and load conditions, feedstocks, expansion allowance, and other basic project characteristics. Next, process units and flow diagrams are specified. This is followed by a steady state flow sheet analysis to determine heat and material balances, stream chemical composition and physical characteristics. This is usually repeated to examine alternative process units and operating conditions.

THE BDM CORPORATION

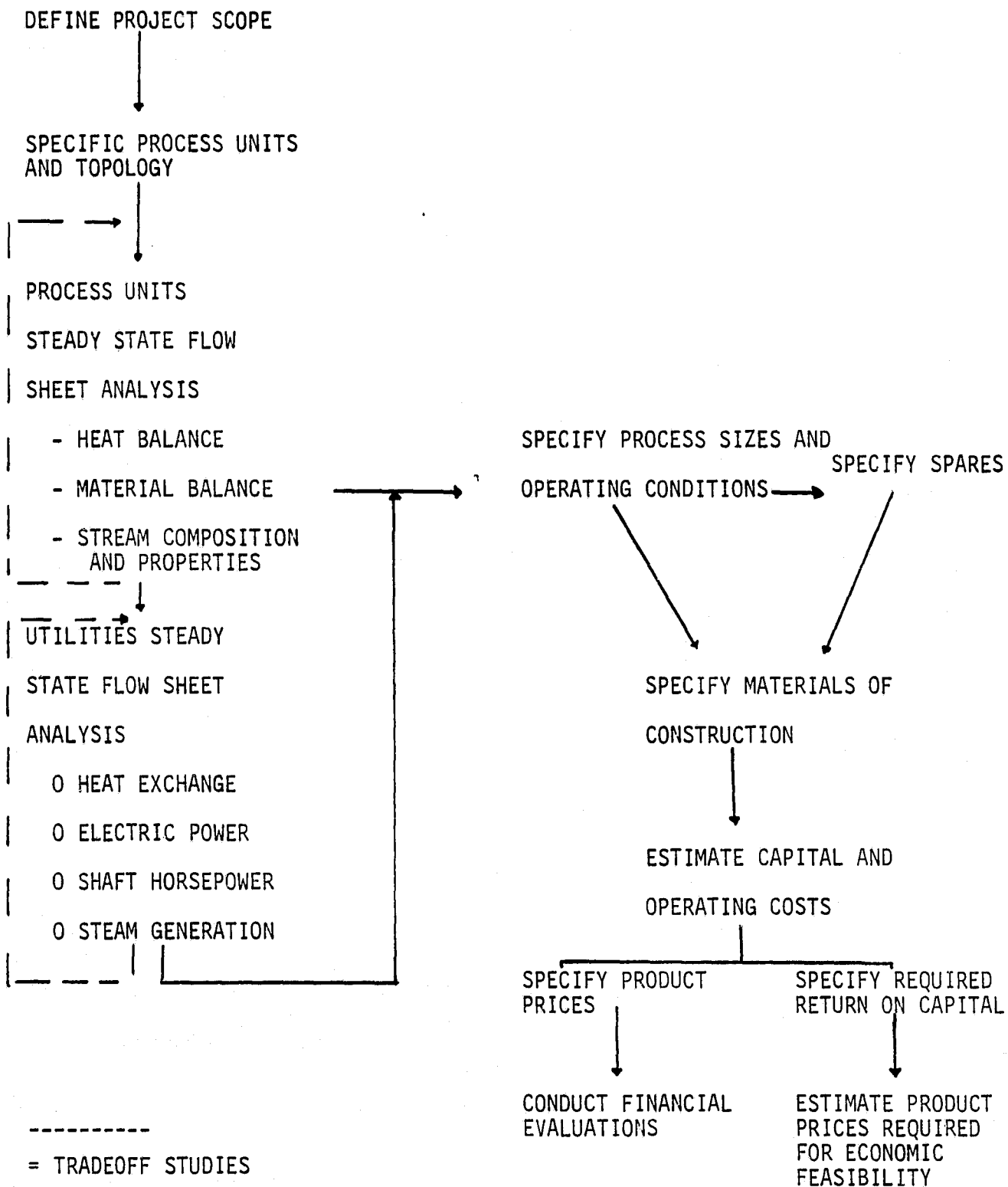


FIGURE II-3 CONCEPTUAL DESIGN OVERVIEW

THE BDM CORPORATION

The next major step is utility analysis, which involves the optimization of steam electricity, shaft horsepower and water or steam heat exchange systems. This step is driven by the design engineer's interpretation of heat and material balances from the steady state process flow sheet analysis. It is based on steady state flowsheet analysis, but oriented toward utilities rather than chemical processes. The analysis may be repeated to examine tradeoffs in these systems. Tradeoffs between process units and utility systems may also be examined through additional case studies of both steady state flows and heat analysis and utility analysis.

After a set of alternative designs has been established, unit sizes and operating conditions are determined. Based on operating conditions and stream corrosive and erosive properties, materials (type of steel, etc.) are specified for each unit. This is a crucial step since variations in materials costs can cause process costs to vary by a factor of three or more.

Based on the system's physical specifications, all capital and operating cost items are identified and costs are estimated. Cost estimates will include actual equipment costs as well as bulk materials, labor and rented construction experiment. Process and project contingencies must also be estimated, especially for new processes or new sizes and combinations of processes.

Finally, a project financial evaluation may be performed, to determine the projected cash flow and rate of return. This requires specification of debt interest rates, debt/equity ratio, projected product prices and sales, and a host of escalation factors. Additionally, the product prices required to achieve economic feasibility may be computed. In this case, the required rate of return on capital must be specified.

3. Modeling Requirements For Conceptual Design

The majority of the computation in conceptual design is a steady state flowsheet analysis, which is almost universally conducted with computer simulation models. The balance of the computations, which represent a substantial effort, are most commonly performed manually, although

THE BDM CORPORATION

financial evaluations (and costing to a much lesser extent) are performed with automated systems. Steady state process and utility flowsheet simulation is by far the most complex and extensive computer modeling analysis widely employed in conceptual design. Financial models are straightforward implementations of net present value computations. Additionally, some designers are turning to highly sophisticated automated systems to develop plant cost estimates.

Another potentially important class of models is gasifier models to predict gasifier yields. The gasifier is the primary type of process unit that cannot be modelled effectively with the kinds of unit operations models commonly provided in steady state flowsheet simulation packages. In the absence of effective gasifier models, the licensor would specify the gasifier yields and duty as inputs to the flowsheet simulations.

Based on these requirements (Figure II-4), Chapter III presents a description of each of these types of models, a survey of available models and recommendations for appropriate models.

It is important to emphasize the need for extensive judgmental human interaction of the engineer in steady state flowsheet simulation. Many engineering decisions are required to achieve a starting point that will converge to a meaningful solution, and user intervention may be required to get the system to converge. For some types of processes, the user may be required to run the simulation, perform some manual calculations based on the results, and repeat this process several times to obtain convergence to a consistent solution. Thus the models are by no means automatic and require an engineer knowledgeable of the process to produce meaningful results.

C. Requirements Analysis - Environmental Modeling and Analysis

1. Overview

Management of environmental aspects of developing a coal gasification plant is a complex process that requires close attention throughout the project. Although there are no accepted standard approaches, a large

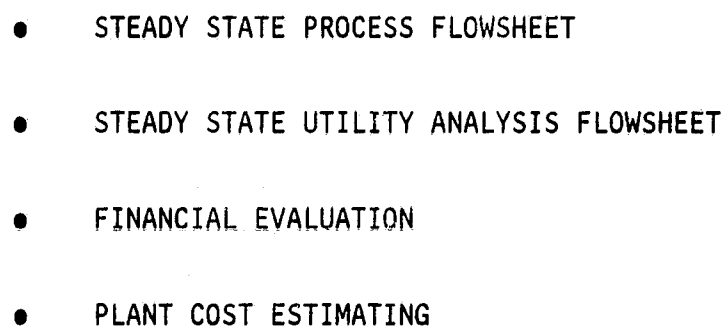
- 
- STEADY STATE PROCESS FLOWSHEET
 - STEADY STATE UTILITY ANALYSIS FLOWSHEET
 - FINANCIAL EVALUATION
 - PLANT COST ESTIMATING

Figure II-4. Modelling Requirements for Conceptual Design

THE BDM CORPORATION

number of models are available to use in this process. This section describes the environmental management process and briefly indicates the available models and how they are used. The models are not discussed further in this report because NASA does not currently plan to conduct environmental studies for the gasification project. It is important, however, to understand the environmental management process and its relationship to the engineering design and development process, as each of these processes will impose requirements and constraints on the other.

2. Management of Environmental Aspects of Siting a New Commercial Coal Gasification Plant

a. Introduction

The year 1969 saw the passage of the National Environmental Policy Act (NEPA), one of the most significant pieces of legislation in the history of our nation. This landmark act has been referred to as the environmental bill of rights as it established a national policy for the protection of the environment. It has caused fundamental change in the way planning is done for new facilities, particularly energy related facilities. In essence, it established the fact that environmental considerations are as important as engineering and economic.

Prior to 1969, the typical planning process for one utility was to first select a source of fuel, then select the most advantageous means of transporting the fuel, and then select a site where a plant could be built to burn the fuel. The plant site was normally purchased through a third party, and no plans were disclosed until just before the groundbreaking ceremony. Environmental planning in this process was usually associated with specific problems associated with the site that might impact on the operations of the facility and was reactive rather than anticipative in nature. The process was so free of external influences that the company could virtually predict the day power could be sold once the decision to build was made.

In 1979, major elements have been introduced into the planning process as a result of NEPA and the many environmental laws, state and federal, that have been triggered by NEPA. An environmental impact statement can be required, and associated with the environmental impact

THE BDM CORPORATION

statement is the process of public participation in the planning process. This seemingly modest provision has been largely responsible for an increase in the planning time of three years and has resulted in bitter adversary actions in which companies are frequently stymied in their efforts to build new plants. The area of concern has been broadened to include all associated actions, such as the construction of power lines and even impacts caused by the mining of the coal for the facility.

Such cases as Kaiparowitz, Seabrook, Storm King, and Blue Ridge are mute testimony to the power of the environmental movement and to the problems faced by the entire energy industry. These projects were all designed to meet the requirements of the existing environmental rules and regulations. The utilities initiated major design and construction activities with the confidence that their planning had been thorough and the necessary permits were forthcoming. However, all of these projects were subject to intense opposition and were either denied permits by public officials or the applications were withdrawn in frustration.

The President, in his recent message on energy, recognized this problem and set as a goal the simplification and the unraveling of the red tape associated with environmental permit applications. There is, however, no indication as to when this will be done, how it will be accomplished, or if it is even possible; so for the immediate future utilities are faced with the same uncertainties they have faced for the past ten years.

There has been a tendency in industry for managers to throw up their hands in despair after being involved in a controversial environmental issue. There are, however, several things that can be done to enhance the prospects of success of a permit application. These actions should be incorporated into a plan for managing the project from the very first day of the decision to study the need for additional plant capacity.

- The plan must recognize the fact of public participation and the eventual opposition to the action by any number of public interest groups and government agencies.

THE BDM CORPORATION

- The plan must have an organized process for dealing with the public that will provide an early warning system for potential problems and a process for evaluating the significance of the problem.
- The managing team must be flexible to adjust to problems encountered and must be willing to modify the preferred course of action or to drop it in favor of another viable alternative.

This approach recognizes that the leverage in the siting process has moved from industry to the public. It also recognizes that a less desirable course of action is preferable to years spent in litigation with the distinct possibility that at the end of the process the application may be denied.

b. Management Program Background and Purpose

In developing plans for a new energy plant, particularly one with major uncertainties associated with it such as a coal gasification plant, it must be assumed that an environmental impact statement will be required for the proposed action. Regardless of how desirable and essential the action may seem, in today's climate someone will oppose the project on environmental grounds. This could negate a substantial engineering effort and result in a significant loss of time or cancellation of the project.

The moment the decision is made to build a plant a project management team should be appointed and a management plan prepared and at least one member of the team should be a professional environmental manager. This task force will be responsible for managing the project through the three stages of planning; conceptualization, study, and final design. Each stage has distinct problems and critical issues that must be addressed if the project is not to be delayed. The management plan should be designed to:

- Get through the regulatory process without delay
- Identify potential problem areas so that modifications can be made

THE BDM CORPORATION

- Provide a record that will stand up in court and permit the courts to act quickly

The plan must be flexible; it must provide for the contingency of new and changing rules and regulations, particularly since there is no formal procedure for permitting coal gasification plants. Planners are faced with a moving target, and compliance is based on current rules and regulations and not on the date of application. An overview of the activities and timing is illustrated in Figure II-5 and each phase is described below.

c. Phase I: Project Conceptualization

Time frame: 6 months

Critical issues:

- The need must be determined and a justification prepared
- All reasonable alternatives to meet the need must be identified
- A preferred system must be selected
- The study area must be defined.

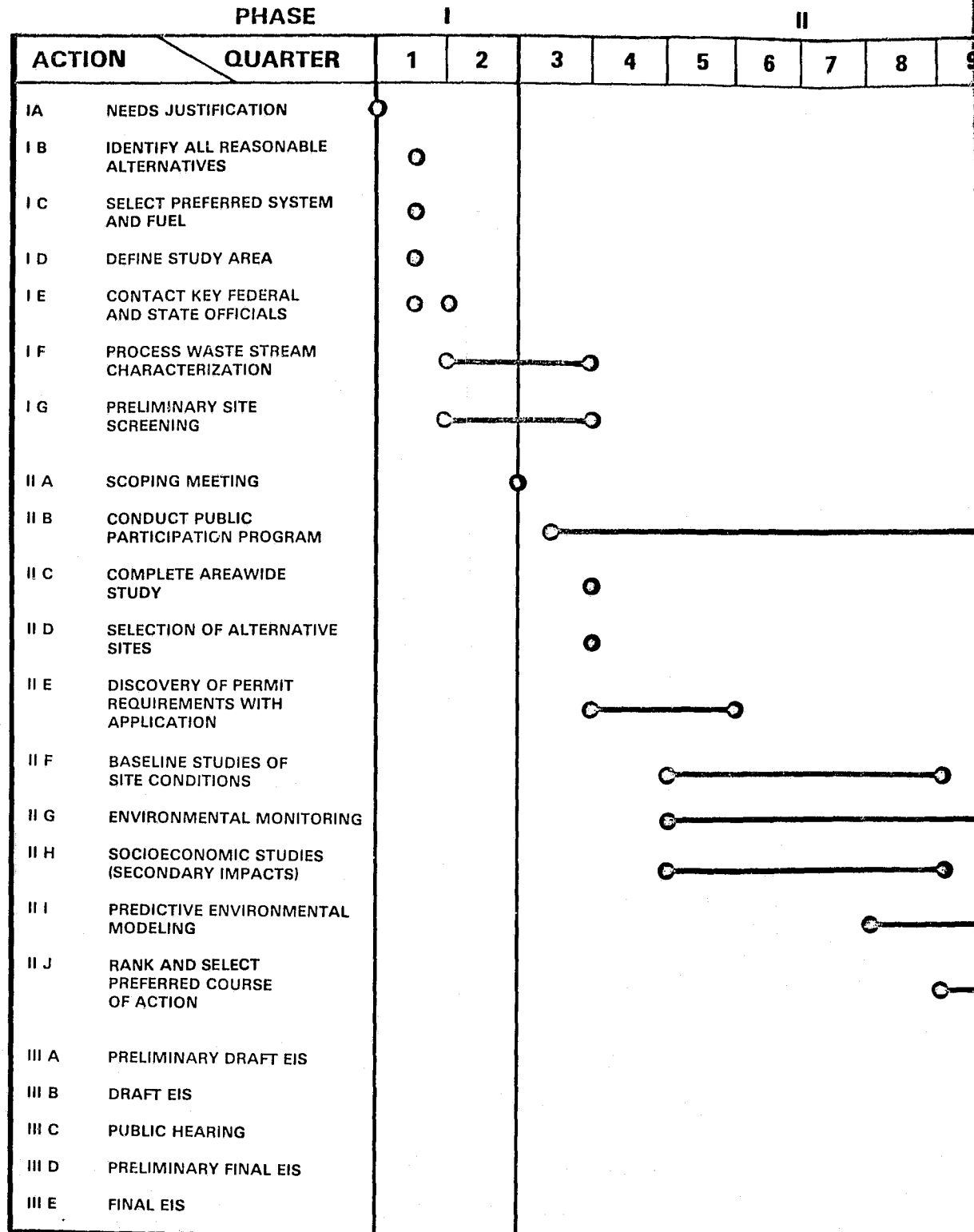
The first step in the planning process is to determine the need for the project. This must be clearly documented and all the alternatives for meeting the need discussed, in accordance with the CEQ guidelines on environmental impact statements. For example, alternatives include power pool arrangements and the many other systems for producing energy. This must be done in an exact and careful manner, as the adversaries to the case will focus on this issue first. Is there a need? The main points that will be addressed by the intervenors will be conservation efforts, and alternative solutions such as energy from such sources as solar, wind, and biomass, including exotics still years away from commercial development. This exemplifies the tactics that will be encountered during the planning process; delay and test each element of the program.

From the array of alternatives, the project team will select the proposed system for development; in this instance, coal gasification. The following items stem from this decision:

- The type of system to be constructed
- The size of the system

Page intentionally left blank

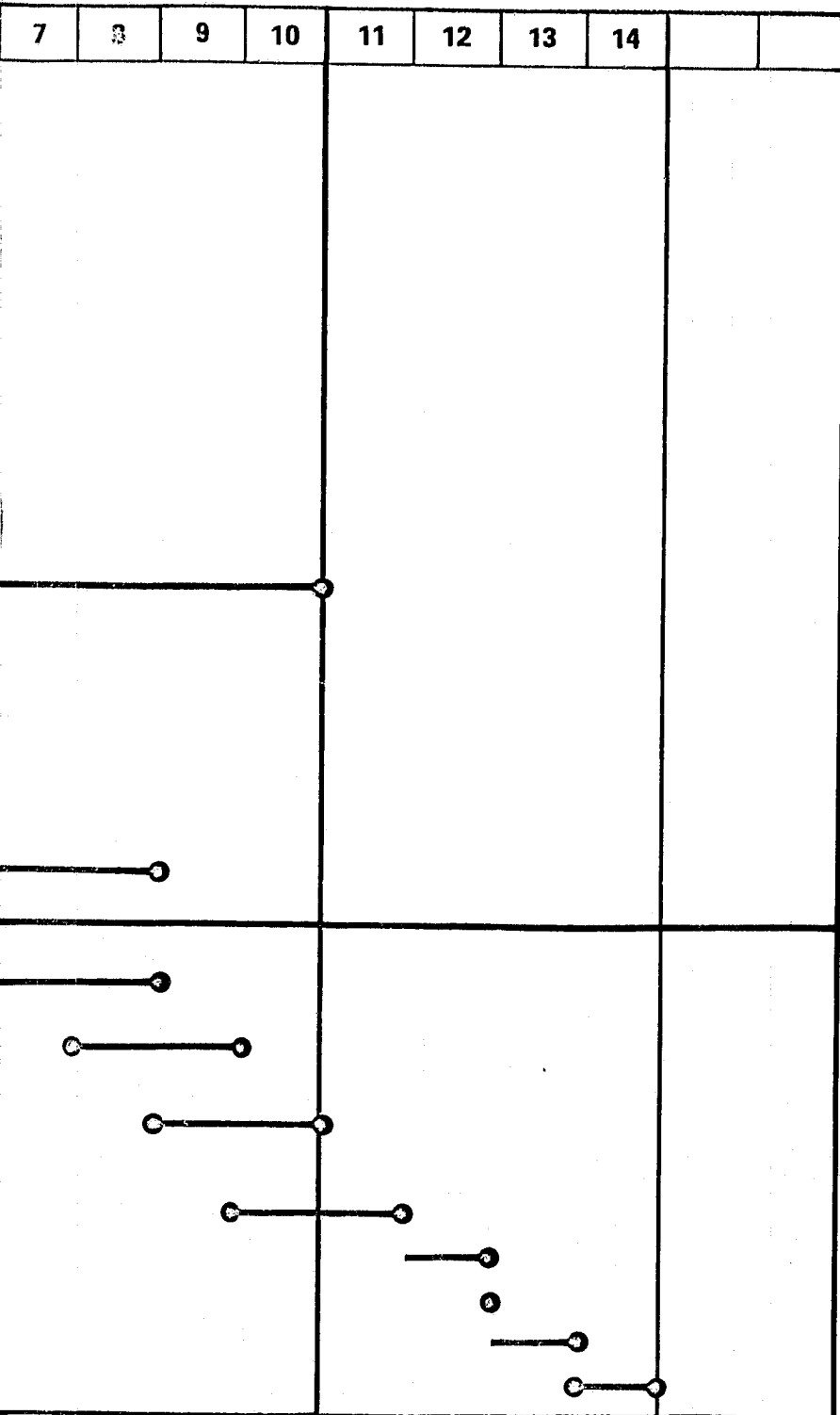
THE BDM CORPORATION



FOLDOUT FRAME

Figure II-5. Overview of Management Plan, A

III



ement Plan, Activities and Timing

FOLDOUT. FRAME

II-15/16

2

THE BDM CORPORATION

- Associated facilities--power generating plant, power lines, station sites, cooling system, waste disposal sites
- Source of fuel.

Once the physical facilities are described, an environmental profile of the project will be prepared. The environmental profile (Attachment A) will contain a preliminary evaluation of:

- Air quality emissions
- Water demand
- Water quality releases
- Noise
- Land use requirements

During this period it is essential to establish early contact with the new source coordinator of the United States Environmental Protection Agency to advise EPA of the preliminary nature of the plan and to alert them to the plans of the potential applicant. This contact will elicit information from EPA concerning the issue that will be useful in the planning process. At the same time, informal contact is made with the federal agency, and the key agency in the state should also be alerted. The purpose of this is to test the regulatory waters and to determine the attitudes and concerns of some of the key people.

The applicant will have to establish a geographical study area which will be based on many considerations. Important considerations include water and land availability, air quality region transportation network, and fuel. The manner in which the zone of consideration is determined must be documented just as carefully as the needs justification.

d. Phase II: Comprehensive Studies

Time frame: 24 months.

Critical issues:

- The applicant must arrange for an early organization of a scoping meeting with the lead federal agency
- A full range of public contacts must be identified and initial contacts established

THE BDM CORPORATION

- All alternative sites must be identified
- Baseline studies of the sites must be conducted
- The preferred course of action must be identified
- All applicable federal, state, and local rules and regulations must be identified.

1) Scoping and Initial Contacts

The Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act call for a scoping meeting to be organized by the lead federal agency early in the process. This meeting "shall be an early and open process for determining the scope of issues to be addressed and for identifying the significant issues related to a proposed action." The applicant should request that this meeting be arranged as quickly as possible, primarily because one of the provisions of this process requires the lead agency to "invite the participating of affected federal, state, and local agencies, any affected Indian tribe, the proponent of the action, and other interested persons (including those who might not be in accord with the action on environmental grounds)."

After the scoping meeting the applicant should develop a program for keeping key people informed as to what progress is being made in the planning process. This serves the very important purpose of providing a means of identifying individuals and groups that might appear in an adversary role in the proposed action. The program should be developed so that the concerns of these groups are clearly identified, so that appropriate actions and studies can be undertaken to answer their concerns and questions. It can also serve the purpose of generating support for the proposed action.

2) Regulatory Analysis

All applicable federal, state, and local rules and regulations must be identified, and procedures initiated to obtain the essential permits. Attachment B lists the major federal legislation applicable to coal gasification. Early application must be made for the Prevention of Significant Deterioration (PSD) permit; this is not a requirement for the environmental impact statement, but the site work associated with obtaining this permit will be useful in preparing the EIS.

3) Data Collection

The data collection effort consists of two parts; a broad area-wide study of certain key elements that isolates the candidate sites, and site-specific studies in order to select the preferred site. Data collection will account for most of the effort in this phase. The data collection will be designed to identify the environmental constraints on siting a plant in various sections of the study area; and to clearly identify the optimum site.

The area-wide study consists of identifying those areas that absolutely can not be considered for development. These are areas that can be considered critical environmental areas such as:

- Public recreation areas
- Scenic rivers
- Primitive areas
- Historic landmarks
- Wetlands
- Critical wildlife habitats
- Non-attainment air quality regions

Important sources of information for the area-wide review are area-wide 208 plans, river basin plans (303 studies), and various studies conducted by regional planning commissions. In addition, all environmental impact statements prepared for actions within the study area should be carefully reviewed and cited where possible. It is not the intent of the federal regulation to redo studies that have been demonstrated to be adequate and factual.

The area-wide analysis will determine the potential sites for further consideration and site specific studies. The site specific studies include such evaluations as:

- Flora and fauna
- Water quality--surface and ground
- Air quality
- Meteorological

THE BDM CORPORATION

- Noise
- Aesthetics
- Soils and geology
- Archaeological

These studies must be comprehensive in nature. The water quality studies will include: volume flows, pH, temperature, suspended solids, coliform bacteria, oxygen demand, dissolved oxygen, nutrients, heavy metals, and toxic substances.

One year of air quality and meteorological data must be developed in order to obtain the Prevention of Significant Deterioration (PSD) permit. This information can be used also in applying for the state air pollution control permit and in the environmental impact statement. The current PSD requirements call for monitoring total suspended solids and sulfur dioxide. In 1980 this list will be expanded to include nitrogen oxides, hydrocarbons, carbon monoxide, and photochemical oxidants.

The information obtained from these studies will be used in predictive environmental modeling to assess the impacts of the proposed facility. In developing the plan for the baseline studies, a period of one year must be allocated in order to evaluate seasonal differences.

A site can be abandoned as soon as it is apparent that it will not meet one of the criteria established by state or federal laws. For example, as soon as a rare and endangered species is found to inhabit a site, serious consideration should be given to eliminating the site from further consideration. This would still be documented in the EIS, but rather than a lengthy description of the site characteristics, a simple statement concerning the find will suffice for the review.

4) Impact Analysis

Concurrent with the site studies, the impacts of the development are evaluated from the secondary impact point of view, i.e., what will happen to the people in the area who will be affected by the development. This will include such studies as the impact on the waste water treatment system, the impact on the need for services, and the impact

THE BDM CORPORATION

on the air quality from sources such as increased auto traffic. This process is designed to avoid areas that do not have the environmental holding capacity and to locate the facilities so that important resources are not adversely impacted, and to permit the engineers to design with aesthetics in mind.

5) Public Involvement

During Phase II there will be frequent and continuous contact with public officials and individuals interested in the project. There should be an organized effort to disseminate information. This could include holding public hearings and meetings to inform the public of the status of the studies and to get feedback on attitudes and feelings. The potential intervenors must be identified, as well as the particular issue they are concerned about. The nature and the frequency of the meetings will depend on the particular area and the controversy engendered. It may be adequate to have meetings in conjunction with local meetings of the town council or the county board of supervisors. It may call for public meetings organized solely for the purpose of discussing the siting of the plant and the related facilities. All contact and interaction with the public must be carefully documented; this will be useful during the later stages when the formal application for permit is made. The importance of public participation is evidenced by the guidelines developed by the United States Environmental Protection Agency guidelines for public participation, and the statement by the Council on Environmental Quality, "NEPA procedures must insure that environmental information is available to public officials and citizens before decisions are made and before actions are taken."

To assist in the public contact and public participation stages and for use as a planning tool, a useful tool is a geographic mapping system. The system must be one that can support manipulation and organization of data, as well as being a visual tool for use with the public to tell the site selection story. This tool would also be used for the selection process of the power plant, power lines, and other associated facilities, such as ash disposal areas and water treatment facilities.

THE BDM CORPORATION

This stage, Phase II, is the most critical from many standpoints, and if it is not properly managed, the adversaries to the action can easily delay the program for years in order to have additional studies conducted or to have studies that are inadequate done over again. One organization spent 13 years in this phase and eventually had to abandon an apparently viable project.

The process of Phase II should be organized with the view that all opposing views must be dealt with and that the record must be developed that will permit the expeditious movement of the record through the regulatory channels and the courts. In essence, the entire Phase II consists of the writing of the environmental impact statement and the review and comment as the process is in progress.

e. Phase III

Time frame: 12 months

Critical issues:

- The draft and final environmental impact statements must be prepared in a concise manner, with simple language that adequately reflects the entire planning process
- The proposed action must be defensible at public hearings
- The plan must hold up under regulatory review.

The process for Phase III is clearly defined. A preliminary draft of the environmental impact statement (EIS) is prepared and submitted it to the lead federal agency. This will be reviewed and, after appropriate comments, modifications will be made and a Draft EIS prepared.

If the program has been properly managed, all major points will have been investigated. This does not mean that the proposed course of action will be routinely ratified and permitted, but it does mean that the critical issues have been identified and are discussed in a substantive way in the formal reports and the planning process. Another key issue is that public feelings and attitudes and suggestions have been taken into consideration--the planning has not taken place in a vacuum. By the same token, when the results are presented in formal fashion, there should be no surprises for those who are interested in or concerned about the project.

THE BDM CORPORATION

The Draft EIS will be circulated to other federal agencies, state agencies, and private organizations for review and comment. At this time, a public hearing may be held if the action is of a controversial nature. Each agency has guidelines for public participation; it is essential that these are adhered to. As a matter of course, during the early phases of the planning process, a systematic and orderly approach to dealing with the private sector should have been planned and implemented. The public hearing is the last element of the process. Of course, this plan will be modified in accordance with the degree of controversy encountered and in accordance with the needs of the specific project.

Once the comments are received from the various reviewers, a preliminary Final EIS will be prepared and reviewed by the lead agency. This will be published as the Final EIS. Subsequent actions and activities will depend on the success of intervenors in having the courts of law assume jurisdiction over the action.

3. Environmental Modeling Requirements

There are no standards or protocols for the use of models in environmental impact assessment, and practices vary widely. There are, however, a large number of models available to support the various impact analyses. The categories of models are listed in Figure II-6, and the timing of their usage is indicated briefly in Figure II-7. This study is focused on engineering design and environmental models are not discussed further in this report.

- SITING
- AIR QUALITY
- COOLING POND AND COOLING TOWERS-THERMAL AND VAPOR PLANE
- WATER QUALITY
- ECOLOGICAL
- SOCIOECONOMICS AND LAND USE

Figure II-6. Categories of Environmental Models

Page intentionally left blank

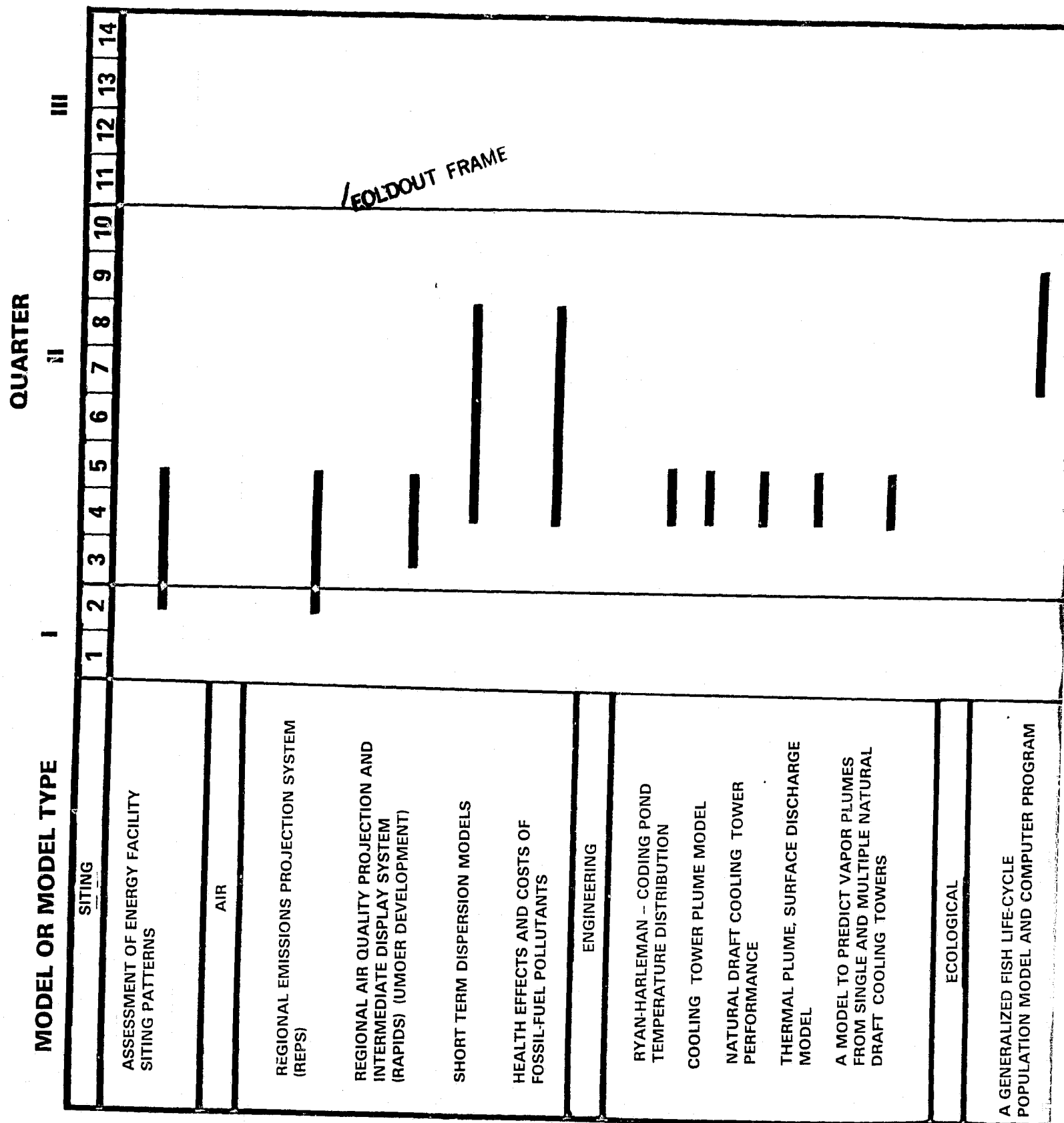


Figure II-7. Schedule for Use of E

<p>ECOLOGICAL</p>	<p>A GENERALIZED FISH LIFE-CYCLE POPULATION MODEL AND COMPUTER PROGRAM</p> <p>MODELING OF POWER PLANT IMPACTS ON FISH POPULATIONS</p> <p>A MODEL TO PREDICT FISH-IMPINGEMENT AT COOLING TOWER INTAKES</p> <p>THERMALLY INDUCED BIOLOGICAL EFFECTS CAUSED BY ONCE-THROUGH COOLING SYSTEMS: A RATIONAL FOR EVALUATION</p>	<p>SOCIOECONOMICS</p>	<p>A LAND SUITABILITY MODEL FOR EVALUATION OF LAND USE CHANGE</p> <p>SOCIAL ECONOMIC AND ASSESSMENT MODEL: COUNTY POPULATION, EMPLOYMENT, HOUSING AND PUBLIC COSTS PROJECTIONS</p>	<p>WATER QUALITY</p>	<p>A MODEL TO PREDICT REGIONAL WATER QUALITY IMPACTS FROM COAL RELATED FACILITIES</p> <p>RIVER BASIN WATER QUALITY MODEL</p> <p>WATER QUALITY MANAGEMENT PROGRAM HYDROLOGY PACKAGE</p> <p>A 3-DIMENSIONAL FINITE ELEMENT MODEL FOR THE MIGRATION OF CONTAMINANTS IN CONFIRMED AND UNCONFIRMED AQUIFERS</p> <p>SIMULTANEOUS TRANSPORT OF WATER AND REACTING SOLUTES THROUGH MULTILAYERED SOILS UNDER TRANSIENT UNSATURATED FLOW CONDITIONS</p> <p>SELECTED DIGITAL COMPUTER TECHNIQUES FOR GROUNDWATER RESOURCE EVALUATION</p>
-------------------	-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------	-----------------------	------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------	----------------------	-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------

2 FOLDOUT. FRAME

D. REQUIREMENTS ANALYSIS - SUPPORTING TECHNOLOGY DEVELOPMENT

1. Introduction

The large scale commercial production of synthetic fuels from coal in the present and predicted economic, social and political environment of the United States represents a major challenge from the viewpoint of technology development. Although there have been several very small coal gasification pilot plants developed and operated in this country, the technological implications of operating a huge 20,000 ton per day coal conversion facility necessarily mean that existing data bases, relevant computer models, metallurgical experience, etc., must be supplemented by a strong research and development effort. This will insure that the best current technology will be utilized and that orderly development of advanced technology proceeds in such a manner as to provide adequate implementation of necessary improvements during the modular construction of the facility.

The purpose of this section is to focus attention on potential technology development issues which may require R&D support in order to improve the performance, reliability, and cost effectiveness of the modular synthetic fuels facility. Such R&D support should begin in the earliest stages of the conceptual design in order to support the detailed design of the first module in the plant. At the same time data bases, simulation results and component operating experience should be acquired to guide a technology development program needed to improve other modules which could be added to the plant in the future. It is quite possible that such a technology program might even discover or develop improvements which could then be retrofitted to the original module.

The contents of this section consist of an identification of supporting technology issues and an accompanying explanation of why these specific items are considered to be potential candidates for new technology development.

2. Summary of Findings

Figure II-8 provides an initial categorization of potential technology development issues related to the design development and

THE BDM CORPORATION

1. GASIFICATION ISSUES
 - a. METALLURGICAL DEVELOPMENT OF GASIFICATION CHAMBER MATERIALS TO INHIBIT CORROSION/ERROSION
 - b. RELIABLE SCALED-UP GASIFICATION CHAMBERS
 - c. IMPROVED OVERALL UNDERSTANDING OF THE CHEMICAL ENVIRONMENT IN WHICH THE SCALED-UP, SPECIFIC GASIFICATION PROCESS OCCURS
 - d. DEVELOPMENT OF AUTOMATED MONITORING AND CONTROL DEVICES TO INCREASE EFFICIENCY AND STANDARDIZE OUTPUT
 - e. EFFICIENT REMOVAL OF SLAG AND COAL TARS TO PREVENT GASIFIER PLUGGING
 - f. EFFICIENT REMOVAL OF VALUABLE CHAR DURING ON-GOING GASIFIER OPERATION
 - g. DEVELOPMENT OF PRESSURIZED NOZZLES AND INJECTORS TO FEED A HIGH-PRESSURE, OPERATING GASIFIER
 - h. DEVELOPMENT OF CATALYSTS WITH LONGER LIFE, HIGH GAS THROUGHPUT AND INCREASED SULFUR RESISTANCE
2. POLLUTION CONTROL AND BYPRODUCT UTILIZATION/DISPOSAL
 - a. DEVELOPMENT OF A PROCESS-SPECIFIC DATA BASE CHARACTERIZING THE FULL RANGE OF POTENTIAL POLLUTANTS AND THEIR COMBINED EFFECT ON THE ENVIRONMENT
 - b. UTILIZATION OF SULFUR BY-PRODUCTS
 - c. AIRBORNE PARTICULATES ENTRAPMENT
 - d. SLAG UTILIZATION/DISPOSAL
3. AUXILIARY EQUIPMENT DEVELOPMENT
 - a. DEVELOPMENT OF LESS EXPENSIVE, MORE RELIABLE METHODS OF SO_x SCRUBBING
 - b. IMPROVED METHODS OF TREATING WATER POLLUTANTS RESULTING FROM GASIFICATION USING STEAM AND OXYGEN
 - c. DEVELOPMENT OF IMPROVED METHODS OF BURNING BY-PRODUCT CHAR TO PRODUCE PROCESS POWER AND STEAM
4. UTILIZATION OF ATMOSPHERIC OXYGEN
5. TRANSPORTATION AND PRODUCT ISSUES
 - a. SIMULATION OF ALTERNATIVE TRANSPORTATION OPTIONS
 - b. PRODUCT STORAGE
6. COAL PREPARATION
 - a. DEVELOPMENT OF NEW GRINDING TECHNIQUES TO MINIMIZE PRODUCTION OF FINE-SIZED COAL PARTICLES
 - b. DEVELOPMENT OF NEW DRYING TECHNIQUES TO MINIMIZE ENERGY CONSUMED IN COAL DRYING

Figure II-8. Supporting Technology Development Issues

THE BDM CORPORATION

operating of a commercial scale synthetic fuels complex. A detailed discussion of each issue listed in this figure is given below. It is important to note that, obviously, some of these issues must receive more intense technology development support than others. Therefore, it should be clearly understood that it is not our intent to imply that all of the issues in this list are of equal importance. However, each issue listed could, to varying degrees, increase the commercial attractiveness of a synthetic fuels, coal-conversion complex if technological improvements were made with respect to that issue.

3. Gasification Issues

a. Metallurgical Development

The coal gasification process imposes severe demands on the materials utilized in the construction of the gasification reactor and other units. The operational environment includes high temperatures, high pressures and corrosive/erosive substances such as pure hydrogen, hydrogen sulfide, organic acids, chlorides and particulate matter. One design issue in large scale gasification is the application and fabrication of suitable materials of construction. Some potential materials problems, and therefore potential R&D areas, are summarized in the following paragraphs.

Hydrogen sulfite (H_2S) is a potentially troublesome compound, particularly in combination with H_2 . Hydrogen sulfite becomes increasingly corrosive to carbon steel at temperatures over $290^{\circ}C$ ($550^{\circ}F$). If H_2 is absent, the utilization of chromium in the steel will result in progressively better resistance to H_2S . Additionally, the chromium-molybdenum steel alloys and the 300 and 400 Series of stainless steels have proven to be sulfur-compound resistant in petroleum refining operations.

The combination of an H_2 and an H_2S environment nullifies the improved corrosion resistance of chromium-molybdenum steels. However, in this case, the 300 series of austenitic stainless steels, containing a minimum of 18 percent Cr and 8 percent Ni, has proven to be corrosion resistant in the oil refining environment.

Other major metallurgical areas of concern with respect to coal gasification include erosion, sliding wear and combined erosion-corrosion. Although the data base associated with these effects is

THE BDM CORPORATION

incomplete, substantial data is available through DOE's Metals Properties Council program and DOE funded pilot plant programs. Where the data base is not complete, the engineering community at this stage of development relies on previous experience and empirical judgments to attack these problems.

The predicted metallurgical performance of various materials utilized to coal gasification has often been determined by extrapolation of previously known petroleum refinery data. However, there are potentially some problems associated with this approach. Little is known at this time of the corrosivity and composition of complex organic substances which may be present in the large scale gasification environment. Therefore, the materials selection should be conservative to provide protection against these compounds.

In a general sense, the following problems with the materials utilized in construction of the coal gasifier shell may occur:

(1) Metallurgical Problems

- (a) decarburization
- (b) aging
- (c) temper embrittlement

(2) Mechanical Problems

- (a) tensile and yield limits
- (b) creep/stress rupture
- (c) fatigue
- (d) fracture

The overall process environment for scaled-up coal gasification is severe. Typical material-related design issues may include:

- (1) Development of materials to construct a large diameter gasifier which must withstand pressures up to 1500 psi.
- (2) Highway shipping limitations which prevent factory assembly of vessels more than 13 feet in diameter or 100 feet long.
- (3) Field fabrication of gasifiers with the resultant problems of welding preheat maintenance, postweld heat treatment, practical and effective nondestructive testing and effective large scale welding techniques.

THE BDM CORPORATION

Refractory linings are required in gasifiers to conserve heat, increase process efficiency, and withstand the high temperatures which are characteristic of the coal gasification process. Manufacturers of refractory materials believe that suitable materials for coal gasification service are now available. However, there may be difficulties associated with refractory materials in particular applications including:

- (1) Leaching of silica by steam
- (2) Carbon disintegration of fire clay brick in a CO atmosphere
- (3) Destruction of alumina silica by alkalies
- (4) Corrosion produced by slag
- (5) erosion/abrasion by particulate matter
- (6) Mechanical failures resulting in hot spots at the shell.

Another possible refractory related problem is absorption of acidic compounds by the refractory lining and the resultant condensation of these compounds behind the refractory lining which in turn results in acidic corrosion of the metallic shell.

Valve problems are also of potential concern. In some instances, pressure is dropped 1000 psi. Such a drop, especially in the presence of a gas-solid-liquid stream, poses a problem which has yet to be solved. In actual experiments, valve life in such an environment has been as little as two weeks. This problem would be mitigated with staged lock koppen for solids let down, but in some instances, 1000 psi drops are required. Other valve problems are related to throttling of gasifier list dirty product gas streams.

The potential material degradation design issues associated with coal gasification are:

- (1) Abrasive wear of metals
- (2) Erosive wear of refractories
- (3) Sulfur attack on steel
- (4) H₂S aqueous corrosion at high pressure and moderate to low temperatures
- (5) CO₂ aqueous corrosion at high pressure and moderate temperatures

THE BDM CORPORATION

- (6) Stress corrosion cracking by chlorides of stainless steels (including precipitation hardened stainless steels)
- (7) H_2S corrosion and hydrogen embrittlement of steel at high temperatures
- (8) CO and H_2 attack at intermediate temperatures
- (9) Decarburization
- (10) Long time metal fatigue and creep at high temperature.

b. Scaled-up Issues

Although the basic coal gasification chemical reactions are similar for each process, the different processes presently under development have unique characteristics. There are important differences in the:

- (1) Pretreatment of the coal
- (2) Coal feeding to the gasifier
- (3) Gasifier configuration
- (4) Method of supplying heat
- (5) Requirements and operation of the CO shift unit

At the present time, the scaling-up of any of the various gasifiers to the anticipated size will introduce uncertainties in operational efficiency, reliability, and maintainability since data are lacking on which process is the best long-term candidate for use on a commercial scale for any given end use. These uncertainties must be minimized by a supporting research and development effort which focuses on (1) prior and present experiences with small-scale pilot plants in the U.S. and other countries, (2) data collected on analogous situations in other industries, such as the oil refinery industry, (3) experiments to collect data to fill critical data gaps, and (4) utilization of computer simulations to model the large-scale reactions and environment of a commercial coal gasification plant.

c. Chemical Processes

There is a general need to initiate a broadly based data collection effort on the chemistry of the entire coal gasification process.

Coal data characterization is critical for the gasification process. Research on the mineral constituents in coal is of particular

THE BDM CORPORATION

importance because of effects on reactor operating conditions, sulfur distribution, materials of construction, environmental problems, and other design features.

Other data needs for gasification processes include vapor-liquid equilibria for quench, partial condensation, acid scrubbing, and impurity recovery from wastewaters; characterization of solid and liquid products; and turbine blade degradation.

Some data needs are being met through projects sponsored by Department of Energy (DOE), Electrical Power Research Institute (EPRI), Gas Research Institute (GRI), Gas Processors Association (GPA), National Science Foundation (NSF), and others. The overall phase equilibrium program would benefit, however, by additional work, by major coordination between sponsoring agencies, and by a lead taken by DOE to insure a balance among: experimental studies on pure compounds and fractions; and development of predictive methods, based both on existing liquids, heterocompounds containing oxygen, nitrogen, and sulfur, and polynuclear aromatics. Programs for thermal and transport properties should be integrated with the phase equilibrium effort.

The compilation of existing standard coal characterization data by IGT for DOE's "Coal Conversion Systems Technical Book" (already underway) is required on coal behavior at temperatures up to 2000°F, or even higher, characterization of mineral reducing gas atmospheres; elucidation of coal structure; accurate relation of heat of combustion to composition; heat effects in coal drying; and other areas.

The fields of solid-liquid separation and the chemical composition of the materials of construction appear to be very active, minimizing the need for new fundamental data programs, except in conjunction with the development of new improved technology. Existing studies in other data need areas are more sparse, suggesting justification for new supporting research and technology development programs. These areas include: coal/oil slurry viscosity and flow; two and three phase flow through reactors; fluidized gas/solids systems; foaming mechanisms in scrubber systems; and distribution of coal impurities between coal and water in slurries.

THE BDM CORPORATION

d. Automated Monitoring and Control

To exercise control over the on-going coal gasification process, it is necessary to provide measuring instruments which provide accurate, real time process data. A technology development program should be initiated to investigate the applicability in measuring process related information under severe operating conditions of such devices as:

- (1) Resistance thermometers
- (2) Elastic metal sensors
- (3) Strain gauges
- (4) Piezoelectric sensors
- (5) Differential pressure flowmeters
- (6) Linear flow meters
- (7) pH-measuring electrodes
- (8) spectrosopes
- (9) Sonic analyzers

Additionally, the utilization of data processing devices such as microprocessors in the monitoring and control process should receive heavy emphasis.

e. Slag and Coal Tar Removal

Slag tap hole freezing and plugging presented difficulties in the U.S. Bureau of Mines and British Gas Council slagging gasifiers.

Coal tar accumulation can plug apertures and cause corrosion. However, some high temperature gasification processes produce no tars or phenols.

f. Char Removal

In a self-sustaining coal gasification plant, the facilities for generating steam, electrical power and oxygen must be included in the design. It would be desirable to use the by-product char from the gasifier as fuel to these units to combat at least the problem of disposing of this by-product.

g. High Pressure Nozzles and Injectors

The major coal feeding methods which have been investigated are lock hopper, slurry, and screw.

THE BDM CORPORATION

The lock hopper feed is technically feasible at the present time. However, valve erosion, due to high differential pressures which would be encountered, may present a maintenance problem in a full scale plant. Periodic compression and decompression required for the lock hopper are other disadvantages of this system.

The slurry feed system offers a continuous feed possibility. However, the slurry system does not appear to be entirely free from technical problems at the present time.

Many of the maintenance problems associated with the lock hopper system are also present in the screw feed system. Screw feeders are most effectively used in low pressure applications.

h. Catalysts

Methanation and shift of the raw coal gas from the gasifier is carried out by catalytic reactors. Relevant R&D efforts in the catalyst area include efforts to:

- (1) Develop sulfur resistant catalyst for combined shift/methanation
- (2) Improve catalyst life and productivity
- (3) Increase catalytic reactor rate and reduce economic cost
- (4) Identify factors related to catalyst deactivation
- (5) Prepare deactivation-resistant catalysts
- (6) Test new catalysts under simulated operational conditions

The main problems with the catalysts are the sensitivity of the catalysts to contaminants which are present in the raw coal gas.

The utilization of catalysts to directly convert coal to gas is another area which should be thoroughly explored. DOE is presently monitoring research programs in this area.

4. Pollution Control and by-product Utilization/Disposal

a. Identification of all Pollutants & Interactions

The large scale operation of a coal gasification plant will result in the production of significant amount of pollutants, including

THE BDM CORPORATION

solids, liquids, gases and sensory irritants such as noise. It is essential that environmental acceptable methods be utilized to dispose of these pollutants. The total process, for example, results in:

- (1) Sulfur dioxide emission and subsequent formation of sulfates and acid rain in the atmosphere
- (2) Carbon dioxide emissions
- (3) Hazardous trace materials emission
- (4) Solid waste disposal
- (5) Impact of minor components (like HCN, SCN, COS, CS₂, etc.) on the performance of control technologies
- (6) Treatability of high-strength organic wastes in biological system
- (7) Impact of total water recycle (zero discharge) on process operability

Generally, there is a lack of process-specific data to characterize the total spectrum of pollutants in the gasification process and its associated auxiliary operations, and to relate the pollutants to gasifier process conditions. In addition, the total environmental impact of the combined effects of these pollutants has not been determined. Therefore, there appears to be an immediate need for an effort to quantitatively predict the total environmental impact of the combined mass of pollutants that will be created by a scaled-up coal gasification process.

b. Utilization of Sulfur By-products

While the desulfurization systems associated with coal gasification processor produce an ultimately marketable by-product of elemental sulfur or sulfuric acid, actual by-product marketing could prove problematic. Sulfuric acid is more energy-efficient to product, but it is more difficult to store and the market is not as diverse as for sulfur. Many countries are virtually self-sufficient in sulfuric acid production. Conversion to elemental sulfur eases storage and transportation problems, but capital costs increase and more energy is consumed. In addition, the North American market for sulfur is not strong, due to the large U.S. and Canadian production of by-product sulfur from refining processes for petroleum and natural gas. With regard to by-product disposal, regenerable FGD

THE BDM CORPORATION

processes eliminate sludge treatment and disposal and product a marketable product, although at a questionable financial return to the industry. Technology efforts in this area could include the novel uses of sulfur and sulfuric acid.

c. Particulates Entrapment

In the gas cleanup sequence water scrubbing is utilized to give additional dust removal and at the same time cool the gas. Water is condensed from the gas, giving a gas liquor containing many contaminants present in the raw gas, including ammonia, H_2S , as well as small amounts of phenols, cyanides, hydrocarbons, etc., and dust. In addition, it is known that certain trace elements are at least partially volatile at gasification conditions; consequently, they may be present in the raw gas and have to be removed. Some condensation and buildup of volatile materials on entrained char or dust can be expected and the potential environmental impacts need to be defined. Many of the volatile trace elements are very toxic, such as arsenic, cadmium, lead, and fluorine. The subject of trace elements calls for special attention. The gas liquor is not released directly to the environment, but goes to waste water treating, and will be discussed in Section 5.5 on auxiliary facilities.

d. Slag Utilization

It is possible that slag may be commercially utilized, if enough R&D effort is expended on this possibility. Possible uses include building blocks for construction, road-making material, and utilization as landfill. Since a large amount of slag will be produced in any coal gasification project, additional R&D spent on slag utilization could result in significant economic savings.

5. Auxiliary Equipment Development

a. Desulfurizers

The presence of sulfur in coal causes corrosive problems in the gasifier, contaminates the resulting gas, and is a pollutant when released into the atmosphere. Therefore, an R&D effort which attempts to develop new, lower cost, more efficient methods of removing sulfur from pretreated or from the gas could be very useful. A need in this area is the

THE BDM CORPORATION

development of a high temperature sulfur removal process that could operate at around 750°F, or greater. This would result in increased process efficiency because cooling and heating of the synthesis gas is greatly reduced.

b. Oxygen Plant

Since O_2 will be required, the economics and efficiency of the scaled-up O_2 generation become important.

c. Water Purification

The primary source of waste water is the quench condensate. The water used for quenching and washing contains a variety of pollutants, depending on the coal type and gasifier technology employed. In general, this stream may be mechanically separated into an organic phase and a water phase. The organic phase contains oils, tars, phenols, cresols, and a variety of other hydrocarbon species. The water phase contains chlorides and dissolved organics such as phenols and cresols. The organic phase may be retained as a by-product, may be recycled to the gasifier, or may be burned as supplemental process fuel. The water phase contains concentrations of organics and inorganics which preclude direct biological oxidation. Extraction with processes such as Lurgi's Phenosolvan process will remove phenols, cresols, etc., to levels amenable to biological oxidation. The extracted phenol may be sold or burned.

Steam stripping will remove volatile components such as hydrogen sulfide and ammonia, which may then be treated as a separate gaseous stream. At this point, the water phase should be sufficiently free of pollutants to permit effective biological treatment in an activated sludge system, trickling filter, or aerated lagoon. While such treatment is generally effective for the residual species in the water phase (e.g., phenols, cyanides, ammonia, and H_2S), specific situations may require the equivalent of tertiary treatment (e.g., absorption with activated carbon) to produce a satisfactory effluent. The unit processes of water effluent treatment, then, are commercially available, although each plant must be configured to meet the specific requirements of the gasification technology within environmental and economic constraints.

THE BDM CORPORATION

d. Char Burning

See Supporting Technology Development Item - Char Removal.

6. Utilization of Atmospheric Oxygen

The oxygen source for combustion is a logical division among coal gasification processes. With water and coal as basic raw materials, every gasification process requires an input of energy to sustain the overall chemical reactions. In the majority of processes, this is accomplished by simultaneous combustion and gasification of the coal feedstock. In an air-blown process, air is fed directly to the gasifier and the product gas contains significant quantities of nitrogen, reducing the heating value. Separation of nitrogen subsequent to the gasification process is feasible, but expensive. The air-blown processes are therefore best suited for consumers who are able to use a low-Btu process fuel. An alternative to using air is to use pure oxygen. The product gas from an oxygen-blown gasifier is applicable to downstream conversions such as Fischer-Tropsch (F-T), methanol, gasoline, and high-Btu SNG production.

Some processes do not rely on simultaneous combustion and gasification to balance process energy demands. The separation of the steps allows air to be used as the oxygen source without nitrogen dilution of the product. Such processes are receiving consideration as a method of supplying medium-Btu gas for refineries, production of limited quantities of syngas, and other uses. COGAS is an example of this process.

7. Transportation and Product Issues

a. Alternative Transportation Options

Initial studies indicate that the first transportation choice for the product gas is a gas pipeline. Over such a pipeline high Btu gas can potentially be transported over large distances (1000 miles) because it can be directly inserted into existing pipelines while low BTU gas would be limited to much shorter distances (200 miles or less). Continued research into the economics of the gas transportation is required.

b. Product Storage

If significant amounts of sulfur and/or sulfuric acid are found to be non-saleable, or only partially saleable, under future market

THE BDM CORPORATION

conditions, then provisions for storing the unsold portion of these by-products must be made. Even if they are completely saleable, it is likely that there will be a lag time between production and final disposition, thus necessitating the development of storage facilities. In certain gasification processes, valuable coal tars will also be produced in commercial quantities. Another major downstream product could be ammonia, which would also require special storage facilities.

8. Coal Preparation

a. Development of New Techniques to Minimize Production of Fine-Sized Coal Particles (Fixed Bed Gasifiers)

Coal which has been shipped from the mines does not consist of the correct size of pieces to be efficiently utilized directly in a coal gasifier. To obtain the correct size of coal fragments, the coal is sent to a crusher which pulverizes it. The coal is then washed and transferred to the primary screens by conveyer belts. The smaller fragments, called "fines," are less than 3/16 inch in size. These fragments are separated from the mainstream by the primary screen, as are the oversize fragments (greater than 1-1/2 inch). Oversize fragments are then reduced by crushers and the fines which result from this treatment are removed by the secondary screen. Finally, that portion which has not been removed is stored for later use in the gasifier.

The fine-sized coal fragments which are produced in this process are presently difficult to process in some gasifiers. Therefore, two potentially useful technology efforts would consist of (1) development of new techniques for grinding coal, which would minimize the production of fine-sized coal particles or (2) development of techniques to process such particle sizes efficiently in the problem gasifier.

b. Development of New Drying Techniques to Minimize the Amount of Energy Consumed in Coal Drying

The purpose of coal drying is to decrease the amount of energy required to ignite the coal. Drying differs from pretreatment in that the coal is not combusted during the drying stage while it is partially oxidized in the pretreatment phase. Coal drying is necessary because of natural water content or because water has been introduced into

THE BDM CORPORATION

the coal mixture in order to wash away the fine particles. Normally drying reduces the moisture content of the coal from approximately 5% of total weight to about 1%. A supporting technology effort in this area which, if successful, would pay off in the form of saving energy is to investigate the possibility of utilizing solar energy to provide at least part of the energy which is required in the coal drying process.

THE BDM CORPORATION

ATTACHMENT A

FEDERAL ENVIRONMENTAL
LEGISLATION APPLICABLE TO COAL
GASIFICATION

THE BDM CORPORATION

FEDERAL ENVIRONMENTAL LEGISLATION APPLICABLE TO COAL GASIFICATION

LEGISLATION	APPLICABILITY TO COAL GASIFICATION
• NATIONAL ENVIRONMENTAL POLICY ACT OF 1969 (NEPA)	• ENVIRONMENTAL IMPACT STATEMENTS (EIS's) MUST BE PREPARED FOR ALL MAJOR FEDERAL ACTIONS SIGNIFICANTLY AFFECTING THE QUALITY OF THE HUMAN ENVIRONMENT.
• NONNUCLEAR ENERGY RESEARCH AND DEVELOPMENT ACT OF 1974	• WATER AVAILABILITY ASSESSMENTS ARE REQUIRED FOR DEMONSTRATION AND COMMERCIAL PLANTS; RESPONSIBILITIES ARE SHARED WITH THE WATER RESOURCES COUNCIL (WRC).
• CLEAN AIR ACT AS AMENDED, 1977	• AMBIENT AIR QUALITY STANDARDS HAVE BEEN SET FOR SO ₂ , TSP, NO ₂ , CO, HC, AND O _x ; MORE ARE BEING CONSIDERED. • NEW SOURCE PERFORMANCE STANDARDS (NSPS) HAVE BEEN PREPARED FOR FIRST GENERATION LURGI HIGH-BTU GASIFICATION PROCESSES (NOT A PART OF ERDA'S PROGRAM). • STANDARDS FOR HAZARDOUS AIR POLLUTANTS LIMIT MERCURY EMISSIONS, WHICH MAY AFFECT WASTE-WATER TREATMENT PLANT SLUDGE. • NSPS AND REGULATIONS FOR THE PREVENTION OF SIGNIFICANT DETERIORATION MAY AFFECT PLANT SITING; SITING IN NONATTAINMENT AREAS MAY REQUIRE AIR EMISSIONS TRADEOFFS AND LOWERED ACHIEVABLE EMISSION RATES. • BEST AVAILABLE CONTROL TECHNOLOGY (BACT) IS REQUIRED OF GASIFICATION DEMONSTRATION FACILITIES.
• FEDERAL WATER POLLUTION CONTROL ACT AMENDMENTS OF 1972	• NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES) PERMITS ARE REQUIRED TO CONTROL WASTEWATER DISCHARGES. • SINCE EFFLUENT GUIDELINES HAVE NOT BEEN DEVELOPED FOR MOST FOSSIL ENERGY TECHNOLOGIES; PERMIT REQUIREMENTS ARE DETERMINED ON A CASE-BY-CASE BASIS TO MEET STATE PLANS. • A "NO DISCHARGE" GOAL HAS BEEN SET FOR 1985.

THE BDM CORPORATION

LEGISLATION

- RESOURCE CONSERVATION AND RECOVERY ACT OF 1976
- TOXIC SUBSTANCES CONTROL ACT (TOSCA)
- SAFE DRINKING WATER ACT
- NOISE CONTROL ACT OF 1972
- OCCUPATIONAL SAFETY AND HEALTH ACT (OSHA)
- COASTAL ZONE MANAGEMENT ACT OF 1972
- MARINE PROTECTION, RESEARCH AND SANCTUARIES ACT OF 1972
- RIVERS AND HARBORS ACT
- NATIONAL HISTORIC PRESERVATION ACT OF 1966
- ENDANGERED SPECIES ACT

APPLICABILITY TO COAL GASIFICATION

- SOLID WASTE DISPOSAL MUST COMPLY WITH MOST STRINGENT AIR AND WATER STANDARDS; MONITORING IS REQUIRED.
- NEW REGULATIONS WILL BE DEVELOPED IN 1-2 YEARS FOR A FEDERAL HAZARDOUS WASTE HANDLING PERMIT SYSTEM AND STATE PROGRAMS FOR NON-HAZARDOUS SOLID WASTES.
- DISPOSAL OF SPECIFIC MATERIALS (e.g., NICKEL CATALYST) USED IN GASIFICATION PROCESSES MAY BE REGULATED.
- WASTEWATER DISCHARGES MAY REQUIRE ADDITIONAL TREATMENT FOR HEAVY METALS OR ORGANIC WASTE IF THEY IMPACT DRINKING WATER SUPPLIES.
- TO PROTECT HEALTH AND WELFARE, AMBIENT NOISE LEVELS ARE RECOMMENDED; THEY MAY BECOME STANDARDS FOR FACILITIES REGULATED BY STATE AND LOCAL GOVERNMENTS.
- HEALTH AND SAFETY REGULATIONS MUST BE MET FOR WORKERS IN GASIFICATION FACILITIES.
- STATE COASTAL ZONE MANAGEMENT PLANS DEVELOPED WITH FEDERAL FINANCIAL ASSISTANCE MAY AFFECT PLANT SITING AND DESIGN.
- PERMITS ARE REQUIRED FOR ACTIVITIES IN WETLAND AREAS, WHICH MAY RESTRICT GASIFICATION FACILITY SITING.
- PERMITS ARE REQUIRED FOR DREDGE AND FILL ACTIVITIES IN NAVIGABLE WATERS, WHICH MAY AFFECT GASIFICATION FACILITIES SITING.
- PROJECTS MUST BE INTEGRATED WITH FLOOD CONTROL, RIVER, AND DAM PROJECTS.
- FEDERALLY FINANCED, ASSISTED, OR PERMITTED PROJECTS CANNOT IMPACT IMPORTANT HISTORIC OR CULTURAL SITES UNLESS NO ALTERNATIVES EXIST.
- IDENTIFICATION OF ENDANGERED AQUATIC AND TERRESTRIAL SPECIES AT A POTENTIAL CONSTRUCTION SITE IS REQUIRED, WHICH MAY AFFECT GASIFICATION FACILITY SITING.

THE BDM CORPORATION

LEGISLATION

- FISH AND WILDLIFE COORDINATION ACT
- WILD AND SCENIC RIVERS ACT

APPLICABILITY TO COAL GASIFICATION

- ANY PROJECT REQUIRING MODIFICATION OF BODIES OF WATER MUST BE REVIEWED TO PREVENT LOSS OR DAMAGE TO FISH AND WILDLIFE.
- PROJECTS MUST NOT DEGRADE THE QUALITY OF WILD AND SCENIC RIVERS.

THE BDM CORPORATION

ATTACHMENT B

NATURE AND SOURCES OF MAJOR
WASTE STREAMS ASSOCIATED WITH
THE GASIFICATION OF COAL

Nature and sources of major waste streams associated with the gasification of coal

WASTE STREAM	PRINCIPAL COMPONENTS	SOURCES	DISPOSITION	PROCESS
Coal dust	Carbon particles	Feedstock crushings and grinding	Containment and recovery	Cyclone separators, bag filters, enclosure
Stack gas	CO ₂ , SO ₂ , M ₂ , O ₂	Steam generation Stack gas cleanup	Treatment/discharge	Wellman-Lord, limestone injection, lime scrubbing, catalytic oxidation, double alkali, Citrate
	Nitrogen	Oxygen generation	Discharge	
Acid gas	H ₂ , CO ₂ , CH ₄ , COS, H ₂ S, H ₂	Product of shift conversion	Sulfur recovery	H ₂ S can be selectively removed from a gas stream by a rectisol hot potassium carbonate, Sulfinol, MEA, DIPA, or similar process. Claus and Stretford processes recover elemental sulfur from H ₂ S rich streams Tail gases from these units can be treated by incineration, Beavon, Wellman-Lord, or SCOT process.
Exhaust emissions	CO, HC, NO _x , particulate	Automobile traffic	Discharge	
Runoff leachings	Pyrites, sediment, oil organic matter Sediment	Feedstock storage Ash ponds Land surface	Treatment/utilization Discharge	Neutralization Settling
Wastewater	Dissolved salts NH ₃ , phenols, cyanide Thiocyanate, BTX	Water treatment Gasification Product of shift conversion Methanation	Treatment/utilization Treatment and reuse	Coagulation Chevron, Phenosolvan, Phosam, biological oxidation
Blowdown	Dissolved salts	Boilers/cooling towers	Treatment and reuse	Chevron, Phenosolvan, Phosam, bio. oxidation
Cooling water	Heat	Heat exchangers	Utilization discharge	Waste heat recover, cooling towers
Sanitary sewage	Organic/nitrogen compounds	Washrooms	Treatment and utilization	Biological oxidation
Rocks and debris		Feedstock cleaning	Disposal/utilization	Landfill/construction material
Tar	COO, DS, SS, CO, CH ₄ , Phenols, NH ₃ , HCN, Thiocyanate, H ₂ S	Gasification	Utilization	Conversion to oil, direct gasification
Char	Fixed carbon, sulfur	Gasification	Disposal/utilization	Gasification, desulfurization, direct combustion
Ash	Inert residue	Gasification, steam generation	Disposal/utilization	Landfill/incorporation in construction materials
Spent catalysts	Cobalt, molybdenum, iron Bauxite Nickel	Shift conversion Sulfur recovery Methanation	Treatment and recovery Treatment and disposal Treatment and disposal	Oxidation
Spend purifying media	Iron or zinc oxide	Final purification	Treatment and disposal	Oxidation
Sludge	Spent carbon Sulfites	Final purification Stack gas cleanup	Disposal Treatment and disposal	
Refuse	Solids, biomass	Wastewater treatment Work areas	Treatment and disposal Treatment and disposal	Dewatering, oxidation, landfilling Incineration, landfilling

Source: U.S. Environmental Protection Agency. 1974. Emissions from processes producing clean fuels. EPA-450/3-73 028.

B-2

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

CHAPTER III
MODELING AND ANALYSIS METHODOLOGIES

A. PURPOSE AND OVERVIEW

The purpose of this chapter is to identify, evaluate and recommend models and analysis methodologies that address the requirements established in Chapter II. Based on those requirements, three categories of models and analysis methods were selected for investigation (Figure III-1); steady state flowsheet simulations, gasifier models, and economic models. Each of these categories is addressed in a section of this chapter.

- STEADY STATE FLOWSHEET SIMULATIONS
- GASIFIER MODELS
- ECONOMIC MODELS
 - COSTING
 - FINANCIAL EVALUATION

Figure III-1. Overview of Chapter III

B. STEADY STATE FLOWSHEET SIMULATION SYSTEMS

1. Overview

The steady state flowsheet simulation system is the major computer modeling tool required to conduct reviews of A/E designs and to perform independent performance and economic tradeoff studies. The following sections give an overview of steady state flowsheet simulation systems, a discussion of selection criteria, a review of available systems, recommendations, and an implementation plan for the recommendations.

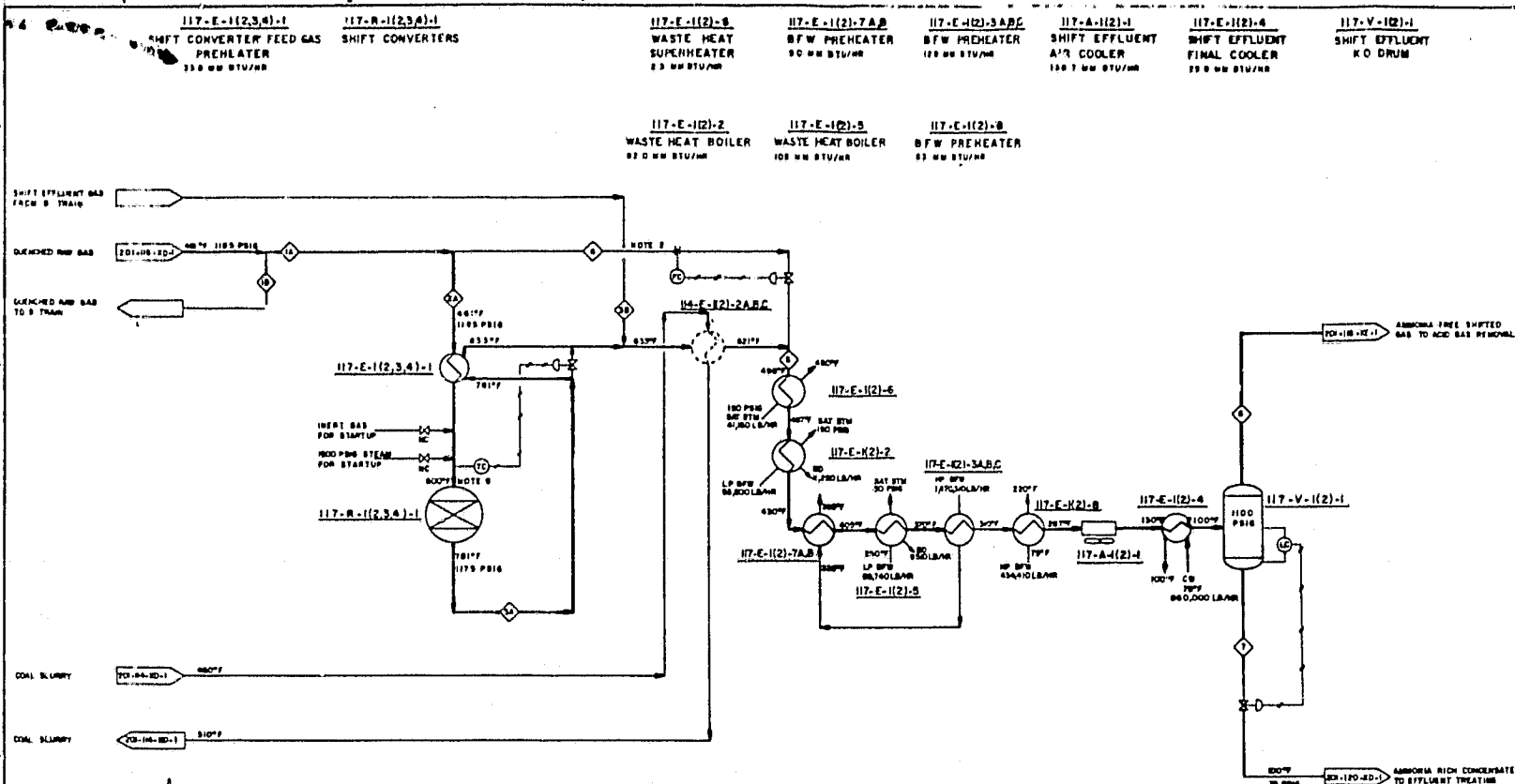
Ideally, a steady state flowsheet simulation system should be available that will model all major processes in a gasification plant, including solids handling, chemical processes and utilities.

2. Overview of Steady State Process Flowsheet Simulation Systems

A steady state process flowsheet simulation system is used to construct models and simulate the characteristics of the physical streams flowing through a process plant under steady state operating conditions. For purposes of this simulation, a plant is characterized as a process flowsheet, as illustrated in Figure III-2. The user modifies this flowsheet slightly to produce a process simulation flowsheet. Major simulation inputs and outputs for chemical processes are listed in Figure III-3. The simulation flowsheet is the basis for one of the major process inputs, the flowsheet "topology," or identification of all process streams and their routes to and from process units. Of course the user must specify all process units to be modeled, and must provide process unit models if they are not in the system's data base. Unit operations models typically provided in a flowsheet simulation package are listed in Figure III-4.

The user must also specify process feed stream characteristics, which would include the characteristics of the feed coal in a gasification plant. The properties that must be specified include the flow rate, chemical composition, pressure and thermal conditions of the feed.

In specifying unit process operations, the user has two choices. The user may specify the process unit operating conditions (temperature,



FOLDOUT, FRAME

STREAM NUMBER	1	2	3	4	5	6	7
STREAM NAME	QUENCHED RAW GAS	GAS TO SHIFT	SHIFT EFFLUENT	SHIFT STEAM	SHIFTED GAS MIXTURE	AMMONIA RICH GAS	AMMONIA RICH CONCENTRATE
COMPONENT							
H ₂	6,176	4,107	6,725	4,158	17,583	17,580	8
CO	5,180	3,452	833	3,476	3,742	5,180	2
CO ₂	5,183	3,453	6,072	3,478	15,622	15,186	437
CH ₄	3,554	2,363	2,363	2,362	7,108	7,103	4
C ₂ H ₆	277	185	185	184	554	554	1
NH ₃	92	61	61	62	184	184	184
H ₂ S/CO ₂	58/2.4	58/1.5	58/0.5	40/1.5	116/2.2	110/2.2	6
C ₂ H ₄	124	82	82	84	248	248	180
TOTAL DRY, LB-MOLS/HR	20,844	13,741	18,560	13,844	40,546	40,741	827
H ₂ O	13,432	8,832	9,313	9,000	27,626	28	21,543
TOTAL WET, LB-MOLS/HR	34,276	22,573	27,873	22,844	68,172	40,779	22,405
TOTAL H ₂ O, LB/HR	713.6	474.5	474.5	474.2	1,421.2	993.3	433.9
TEMP °F	46.1	46.1	181	46.1	498	100	100
PRESS. PSIG	1,185	1,180	1,175	1,185	1,180	1,100	
VEL. FT	20.9	20.9	20.9	20.9	21.7		
WCCFH	11.42	8.61	8.61	8.61	25.85	12.38	
WCCFH							670

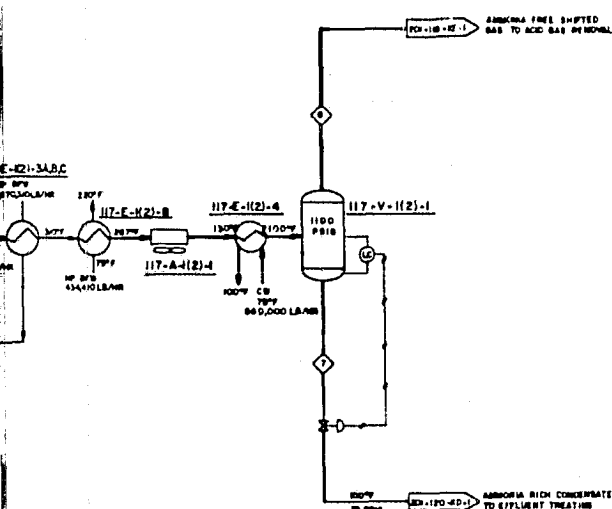
REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

Figure III-2. A Process Flowsheet for a Shift Reactor in a Hy-gas SNG

117-V-102)-1
SHIFT EFFLUENT
KO DRUM

NOTES

- 1 THE SHIFT MECHANISM CONSISTS OF TWO PHASES, ONE THATS WITH THE 20% CAPACITY SHIFT CONDITIONS EACH
- 2 BYPASS FLOW IS VARIED TO MAINTAIN AN H_2 TO CO RATIO OF 3.47 TO 1.0
- 3 SHIFT CONVERTED CONDITIONS SHOWN ARE FOR CATALYST ACTIVATED TO A 30% APPROXIMATE TO EQUILIBRIUM CONVERSION
- 4 THE INTERNAL BALANCE FROM C_1 TO C_2 IS FOR A 25% CAPACITY TRAIN IN
THE INTERNAL BALANCE FROM C_2 TO C_3 IS FOR A 50% CAPACITY TRAIN
- 5 THE ATMOSPHERIC PRESSURE IS 13.0 PSIA
- 6 CONDITIONS SHOWN ARE FOR START OF RUN WITH 30% NOT GAS BYPASSED AT END OF RUN FLED OUTLET WILL BE 66.2% WITH THE NOT BYPASS CLOSED
- 7 TOTAL CAPACITY OF THE PLANT IS $250 = 10^3 \text{ BTU/STREAM HRT OF PIPELINE QUALITY GAS}$



THIS DRAWING IS FOR ESTIMATING
PURPOSES ONLY AND IS NOT TO BE
USED FOR CONSTRUCTION OR FABRICATION

295

DATE	TIME	FROM	TO	CLASS	REMARKS
NOTES					
<p>THIS MESSAGE IS A RELEASE OF THE UNITED STATES GOVERNMENT AND IS NOT TO BE USED FOR ANY OTHER PURPOSES. IT IS THE PROPERTY OF THE UNITED STATES GOVERNMENT AND IS LOANED TO YOU. IT IS TO BE RETURNED TO THE UNITED STATES GOVERNMENT. IT IS TO BE KEPT IN A SAFE PLACE AND NOT TO BE REPRODUCED OR TRANSMITTED IN ANY FORM OR BY ANY MEANS, ELECTRONIC OR MECHANICAL, INCLUDING PHOTOCOPYING, RECORDING, OR BY ANY INFORMATION STORAGE AND RETRIEVAL SYSTEM.</p>					
SECURITY CLASSIFICATION					
BY	DATE	CLASSIFICATION	REASON		
TTC	8 JUL 68	SECRET	11/1/1		
<p>COAL CONVERSION AND UTILIZATION/AMERICAN GAS ASSOCIATION AT WASHINGTON DC</p>					
<p>COMMERCIAL CONCEPT DESIGN-WESTERN COAL IGT STEAM-OXYGEN MYGAS PROCESS SHIFT CONVERSION PROCESS FLOW DIAGRAM</p>					
<p>ALABAMA C F BRAUN & CO CALIFORNIA</p>					
SCALE	REFERENCE NUMBER				PROJECT
ONE					
DATE	4568-201-117-D-1				0
3-1-76					

2 FOLDOUT FRAME

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR.

THE BDM CORPORATION

MAJOR USER INPUTS ARE:

CASE DEFINITION

- PROCESS UNITS (AND MODELS)
- FLOW SHEET TOPOLOGY
- PROCESS PARAMETERS OR PERFORMANCE CRITERIA
- PROCESS FEED STREAM CHARACTERISTICS
 - FLOW RATE
 - CHEMICAL COMPOSITION
 - THERMAL CONDITION

CHEMICAL COMPONENT CHARACTERISTICS

- THERMODYNAMIC PROPERTIES
 - VAPOR/LIQUID EQUILIBRIUM
 - ENTHALPY
 - ENTROPY
- TRANSPORT PROPERTIES
 - VISCOSITY
 - THERMAL CONDUCTIVITY
 - SURFACE TENSION

THE MODEL SOLVES FOR:

CHARACTERISTICS OF ALL PROCESS STREAMS:

- CHEMICAL COMPOSITION
- FLOW RATE
- TEMPERATURE
- PRESSURE
- PHASE
- ENTHALPY

PROCESS PARAMETERS (If Performance Criteria Are Specified)

- PRESSURE
- TEMPERATURE
- DUTY

DERIVED PROPERTIES

- PROPERTIES DERIVED FROM PROCESS STREAM AND CHEMICAL COMPONENT CHARACTERISTICS

Figure III-3. Steady State Flowsheet Model Inputs and Outputs for Chemical Processes

THE BDM CORPORATION

TYPICAL UNIT OPERATIONS MODELS

SOLIDS HANDLING

HOIST
MAGNETIC SEPARATOR
CALIBRATION CHAIN
SCALE
SAMPLER
FEEDER
CONVEYOR
BUCKET ELEVATOR
GRINDER
CRUSHER
DUST COLLECTOR
SCREEN
ROD MILL
SLURRY MIXER
SLURRY PUMP

CHEMICAL PROCESSES

DISTILLATION COLUMN
COMPRESSOR
EXPANDER
FLASH DRUM
HEAT EXCHANGER
STREAM MIXER
PUMP
REACTOR
COMPONENT SEPARATOR
SHORTCUT DISTILLATION
STREAM SPLITTER
VALVE

UTILITIES

CONDENSOR
TURBINE STAGE GROUP
PIPE
GENERATOR
SHAFT
HEAT EXCHANGER
VALVE
BOILER
COMBUSTOR
SUPERHEATER
ECONOMIZER
DEAERATOR
STEAM REHEATER
COMPRESSOR
GAS TURBINE

Figure III-4. Typical Unit Operation Models in a Steady State Flowsheet Simulation

THE BDM CORPORATION

pressure, etc.) and let the model solve for the output stream composition and physical characteristics. Alternately, the user may specify the process unit output and stream composition and characteristics and let the model solve for the corresponding operating conditions. Both of these capabilities are clearly of extreme importance in validating an A/E's process design.

Chemical process simulation systems are equipped with a standard data base describing chemical component characteristics over a wide range of temperature and pressure conditions. The user must supply this information for any needed chemicals that are not included in the data base. The characteristics include thermodynamic properties (vapor-liquid equilibria, enthalpy, entropy), and transport properties (viscosity, thermal conductivity, surface tension).

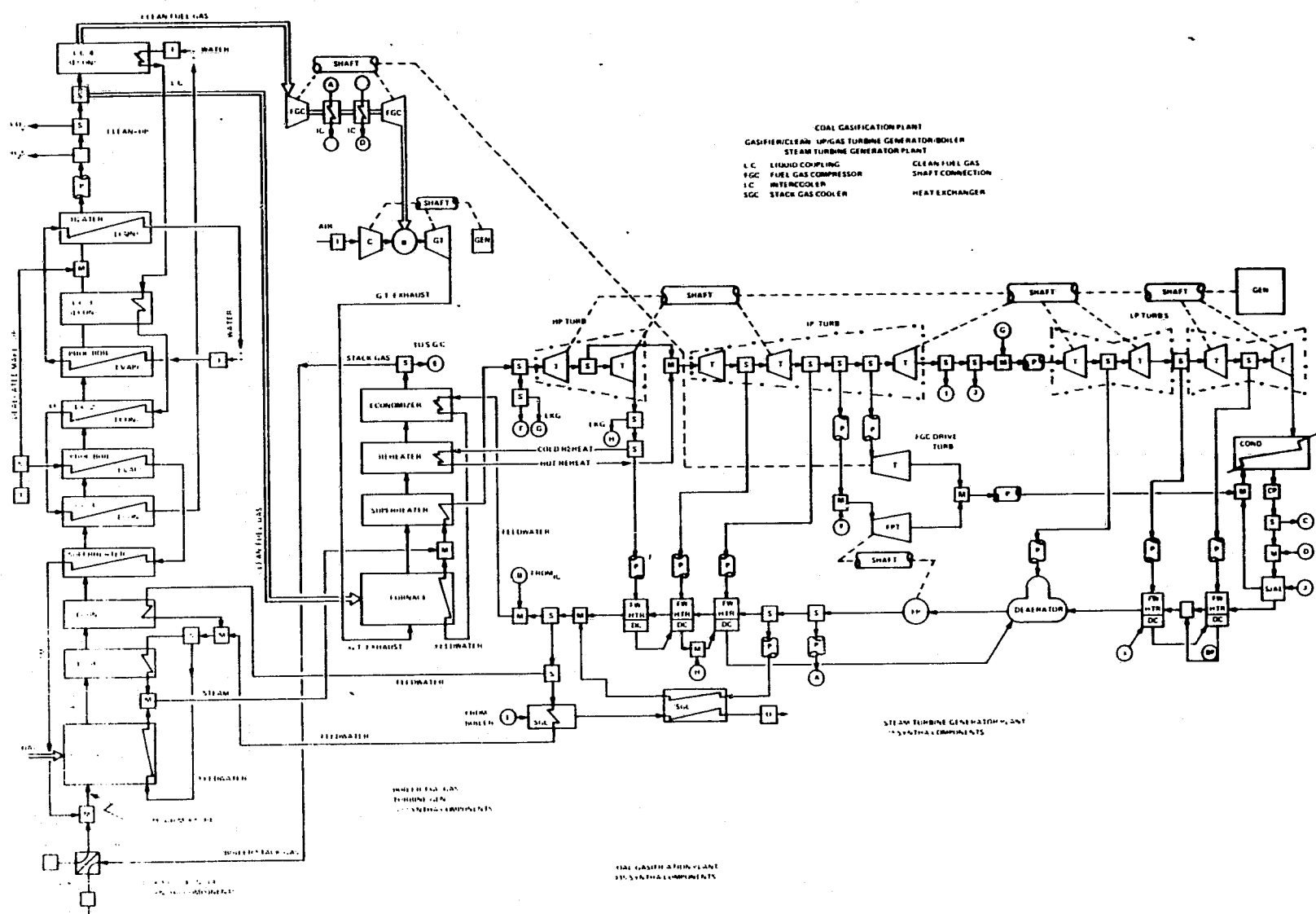
Given these inputs, the model solves for characteristics of all process streams and process unit operating parameters, if specified. Process stream characteristics include chemical composition, flow rate, temperature, pressure, phase, and enthalpy. The model will also compute derived properties such as sizing for process units and heat exchangers.

All inputs are specified in an English-like user language. Problem specifications and solutions may be saved on computer files for subsequent retrieval or modification.

Solutions to base cases usually serve as excellent start points for sensitivity analysis cases, leading to rapid convergence to feasible solutions. A variety of output summaries is available for both detailed and summary examination of results.

Steady state flowsheet packages are also available for simulating the utility processes in a chemical plant; steam and electric power generation, shaft horsepower, heat exchangers, condensers and piping. They are similar in every respect to chemical process steady state flowsheet simulations, except that their data bases and unit operations models are oriented to utility processes rather than chemical processes. An example of a gasification plant utility flowsheet that has been simulated in the synthetic model is shown in Figure III-5.

III-8



Source: Syntha II User Manual, By Permission
 of Control Data Corporation

Figure III-5. Syntha Flow Sheet for a Combined
 Cycle Gasification Plant

Finally, some systems provide the capability to model solids handling processes. Depending on the plant design, these may include many of the items shown in Figure III-4.

Considerable judgment is required to use these systems effectively. The user should provide a reasonable initial guess for material balance, and in some cases may require side calculations to aid the system in obtaining convergence for some of the more complex process unit models. Top quality vendor support is essential in helping the user to meet these requirements.

3. Model Selection Criteria

There are five major criteria, listed in Figure III-6, that a steady state flowsheet simulation must meet to satisfy the requirements set forth in Section B of Chapter II for performing design studies, reviews of A/E designs and economic studies.

First, the system must be able to simulate process stream characteristics and process unit operating conditions. As explained in Chapter II, this capability is required to verify the reasonableness of the design. It is also required to obtain meaningful cost estimates in trade-off studies. For example, the capital and operating costs can vary enormously depending on the electric power, shaft horsepower and process steam requirements for differing combinations of process units and utility subsystem designs. To analyze these costs effectively, both chemical process unit and utility flowsheet analyses are required.

Second, the selected simulation systems should be actively used in the process and/or utility industries. This is the only way to ensure that the data base and unit operations models are sufficiently extensive and thoroughly tested in industrial designs that were subsequently built and operated commercially. Due to the complexity of these systems and their data bases, there is no other practical and timely method for validating the candidate systems.

Third, to ensure effective software, as well as unit models and data bases, the system should have a large, active user community. A

THE BDM CORPORATION

- SIMULATES PROCESS STREAM CHARACTERISTICS AND UNIT OPERATIONS CONDITIONS FROM FLOWSHEET SPECIFICATIONS
 - CHEMICAL PROCESSES
 - UTILITIES
- ACTIVELY USED IN PROCESS INDUSTRY/UTILITY INDUSTRY
 - EXTENSIVE RELEVANT DATA BASE AND UNIT OPERATIONS MODELS
 - SHAKEN DOWN THOROUGHLY IN INDUSTRIAL DESIGN PROJECTS
- LARGE, ACTIVE USER COMMUNITY
 - FUNCTIONAL SOFTWARE
 - EFFECTIVE VENDOR SUPPORT
- ACCOMMODATES COAL-ORIENTED PROCESSES
- OPERATIONAL COAL SIMULATION SYSTEM AVAILABLE IN TIMELY MANNER

Figure III-6. Selection Criteria for Steady State Flowsheet Simulation System

THE BDM CORPORATION

simulation system consists of three inseparable elements: the models and data bases, the software package and the vendor's support organization. Every system contains numerous defects and shortcomings that will require both debugging and modifications to the user's specifications. Additionally, the user will regularly require vendor assistance to use the system effectively. A large, active user community is the only meaningful indicator that the vendor has established a track record of effective support, and that the software works well enough most of the time to serve the user's needs. The user community can be within a large private firm, or a client community.

Fourth, the systems must be able to accommodate coal-oriented process unit models, chemistry and thermodynamics. Preferably, these should already be incorporated in the system. If not, the vendor should have the capability to add them to the system.

Finally, the existing systems plus any required modifications should accommodate a coal conversion system simulations in an acceptable timeframe.

4. Available Steady State Flow Sheet Simulation Systems

The available steady state flow sheet simulation systems fall into the four categories shown in Figure III-7. A detailed catalog describing each system is provided in Appendix B.

Software system vendors are firms whose product is simulation systems, usually licensed through a time-sharing computer network and also offered for lease on the user's own computer. The vendors also supply software support and assistance in solving modeling problems. Syntha II which is a utility-oriented steady state flowsheet simulation system, is widely used and well regarded in the utility industry and is the only such system available. (An example of a recent application of SYNTHA II to gasification plant utilities is shown in Figure III-5.) Of the four steady state flowsheet simulations available through software vendors, three are used by the chemical or refining industry; SSI-PROCESS, Chemi Share-Design and Phillips PDA and GPS systems. There are three essential capabilities

THE BDM CORPORATION

SOFTWARE SYSTEMS VENDORS

- DESIGN (CHEM SHARE CORPORATION)
SSI/100 PROCESS SIMULATOR
(SIMULATION SCIENCES, INC.)
- GPS II AND PDA (PHILLIPS PETROLEUM)
PROCESS SIMULATION PROGRAM
(SIMULATIONS SCIENCES, INC.)
- SYNTHA II (CONTROL DATA CORPORATION)
- SYNTHA III (SYNTHA CORPORATION)

PRIVATE CONSULTING FIRMS

- CHEM E SIMUALTOR (PETROCHEM CONSULTANTS, INC.)
- FAST (GLOBE ENGINEERING COMPANY)
- GPFS (SUNTECH, INC.)
- MPPM (IR & T CORPORATION)

INDUSTRIAL FIRMS

- FLOWSIM (BASF AG)
- FLOWTRAN (MONSANTO COMPANY)
- PATT (BAYER AG)
- PROCESS (DRAVO CORP.)
- PSX (MITSUI TOATSU CHEMICALS, INC.)
- RHONE-POULENC INDUSTRIES PROGRAM PACKAGE
(RHONE-POULENC INDUSTRIES)
- RUMBA (Kennecott Copper Corp.)
- SIMUL (R AND D CENTER OF THE CHEMICAL INDUSTRY, BEDAPEST,
HUNGARY)
- TISFLO (DSM, NETHERLANDS)

Figure III-7. Steady State Flowsheet Simulations

THE BDM CORPORATION

UNIVERSITIES

- AGPSS (UNIVERSITY OF MICHIGAN)
- ASPEN (M.I.T.)
- CHESS (UNIVERSITY OF HOUSTON)
- CHEMICAL PROCESS SIMULATOR
(GEORGIA INSTITUTE OF TECHNOLOGY)
- CHEMOS (UNIVERSITY OF BRITISH COLUMBIA)
- SUCES (UNIVERSITY OF SYDNEY)
- CONCEPT (UNIVERSITY OF TEXAS)
- EBP-II (PURDUE UNIVERSITY)
- ENGBAL (UNIVERSITY OF FLORIDA)
- EXEC (DELFT UNIVERSITY OF TECHNOLOGY)
- GEMCS (UNIVERSITY OF WESTERN ONTARIO)
- MBP-II (PURDUE UNIVERSITY)
- MOSES (UNIVERSITY OF WESTERN ONTARIO)
- PROCESS ANALYSIS SYSTEM (OKLAHOMA STATE UNIVERSITY)
- PROPS (UNIVERSITY OF MISSOURI)
- SIMUL-UNT (UNIVERSIDAD NACIONAL, TUCUMAN, ARGENTINA)
- SEPSIM (UNIVERSITY OF WATERLOO)
- STEADY STATE SIMULATION SYSTEM (PURDUE UNIVERSITY)
- SPAD (UNIVERSITY OF WISCONSIN)
- SYMBOL AND SYMBOL-WITH-BOUNDS
(COMPUTER AIDED DESIGN CENTER, CAMBRIDGE, ENGLAND)

Figure III-7. Steady State Flowsheet Simulations (Continued)

THE BDM CORPORATION

essential to NASA that are not provided in any of these software vendors; chemical process flowsheet simulations systems:

- (1) Three-phase flash calculation algorithm which can be embedded in all model unit operations blocks.
- (2) Data on the behavior of systems containing aqueous electrolytes, which can be processed by the simulator.
- (3) Capability to model multicomponent simultaneous reaction equilibria.
- (4) Capability to use math-logic type processing to manipulate data generated and stored by the simulator.

Three-phase flash calculations are needed in simulation of gasifier quench systems and oil-water separation systems, to properly account for the distribution of critical compounds to the three-phases. This routine must be able to handle the problem of dissociation of aqueous electrolytes and its effect on the compositions of the other phases.

The dissociation of electrolytes in the aqueous phase lowers the volatility of the species which dissociate. Addressing this is of importance in modeling sour water systems, including shift condensation, sour water stripping and raw gas quench. In a three-phase mixture, by lowering the volatility of these electrolytes, dissociation tends to create an imbalance in the mole fractions of the undissociated portions of these components which "pulls" more of these components out of the vapor and hydrocarbon liquid, into the water, than would be predicted by a model which does not account for dissociation. This can have a significant effect on the design of downstream facilities such as acid gas removal, sour water stripping, and sulfur recovery.

Multicomponent reaction equilibria are important in methanation and shift reactions and possibly in catalytic upgrading of liquid byproducts as well. Such a capability could also be used to model a boiler to complete the simulation of the steam and power system and link it with the main process model for optimization studies. The approach to multiple simultaneous reaction equilibrium could be handled by a free-energy

THE BDM CORPORATION

minimization technique with some provision made for approaches to equilibrium.

The developers of SSI-PROCESS have been investigating methods for implementing their capabilities within the SSI-PROCESS system. Another capability that will be highly desirable is simulation of solids handling. Only rudimentary solids handling is presently provided in the available simulation packages. MIT's ASPEN system, soon to be released in a test mode, is reported to have an advanced solids handling simulation capability. Although FLOWTRAN is no longer offered and supported publicly, MIT purchased the highly regarded FLOWTRAN system from Monsanto Company as the basic software system for ASPEN. MIT has completely rewritten the executive software and has developed their own models and chemical and process data base. The ASPEN system will be available on a "test" basis this Fall (1979) but is not likely to be fully operational until at least 1981. ASPEN contains many unique coal conversion-oriented models that will be of interest; such as: solids handling, multi-reactant modeling, and electrolyte dissociation.

Private consulting firms use systems primarily for their own studies and will, in some instances, offer them for lease to users, with the objective of selling the users additional consulting services that may or may not be model-related. Their primary business is usually consulting rather than software development and support.

Many industrial firms have developed modeling systems for their own use. Most of these are proprietary. An exception is Phillips Petroleum, as discussed previously, who licenses their GPS and PDA packages through McDonnell-Douglas automation.

Universities usually develop systems for their own research and consulting studies. The models and data bases are heavily biased toward the Universities' research interests. A notable exception is the ASPEN system now under development at the Massachusetts Institute of Technology under Department of Energy (DOE) sponsorship. DOE's objective is to make widely available a coal conversion-oriented steady state flowsheet simulation system.

5. Recommendations For Steady State Flow Sheet Simulation

To obtain the full range of required steady flow sheet simulation capabilities, the following actions are recommended, as summarized in Figures III-8 and III-9.

a. Obtain Access to SSI-PROCESS, SYNTHA II and ASPEN

Based on the selection criteria described earlier, it is recommended that only systems provided through software vendors be considered, unless a required capability is available only through another source. Of the chemical process simulations available, the SSI PROCESS system satisfies all the selection criteria. Of particular note, SSI has conducted preliminary investigations and could implement additional needed capabilities (shown in Figure III-8) within a few months. SYNTHA II will satisfy the requirements for utility simulation and will not require any modifications.

The ASPEN system, when completed, will address the need for both solids handling and chemical process simulation. ASPEN, however, will not be fully tested for a year or more. Use ASPEN would provide experience with its unique solids handling and chemical process capabilities, and make use of these as appropriate. At a later time, some of these capabilities may be incorporated into SSI-PROCESS or SYNTHA-II.

Access to SSI-PROCESS and SYNTHA-II are obtained by subscribing to one of the time sharing networks through which the systems are licensed. The networks will provide access to computer time, user manuals and training. Alternately the system may be leased directly from SYNTHA and SSI for operation on in-house computers.

Access to the ASPEN system is arranged through the ASPEN project at MIT.

b. Obtain the Following Modifications to SSI-PROCESS

- (1) Add a unit operations model for a three phase flash with electrolyte dissociation in the water phase. The three phases are vapor liquid, hydrocarbon, and liquid water with electrolytes and organics. This is required to model the quench and other separation units.

THE BDM CORPORATION

<u>RECOMMENDED ACTION</u>	<u>SATISFIES REQUIREMENT FOR</u>
I. OBTAIN ACCESS TO THE FOLLOWING MODELING SYSTEMS	
● SSI-PROCESS	- CHEMICAL PROCESS SIMULATION
● SYNTHA II	- UTILITY SIMULATION
● ASPEN*	- SOLIDS HANDLING AND CHEMICAL PROCESS SIMULATION
II. OBTAIN THE FOLLOWING MODIFICATIONS TO SSI-PROCESS:	
● THREE PHASE FLASH WITH ELECTROLYTE DISSOCIATIONS	QUENCH AND OTHER SEPARATIONS
● ADD COMPONENTS TO COMPONENT DATA BASE	REQUIRED FOR THREE PHASE FLASH (QUENCH) AND GAS CLEANUP MODELING
● MULTICOMPONENT REACTION EQUILIBRIUM	SHIFT, METHANATION AND OTHER REACTIONS

*LIMITED NEAR-TERM AVAILABILITY

Figure III-8. Recommendations for Steady State Flowsheet Simulations

THE BDM CORPORATION

ELECTROLYTE COMPONENTS

*NH ₃	CRESOL
*CO ₂	XYLENOL
*H ₂ S	ACETIC ACID
*HCN	PROPIONIC ACID
*SO ₂	BUTYRIC ACID
*PHENOL	OTHER ORGANIC ACIDS
	METHANOL
*FORMIC ACID	ETHANOL
*HCL	ACETONE
*COS	ISOPROPANOL
*METHYL MERCAPTAN	NACL
ETHYL MERCAPTAN	KCL
CS ₂	THIOPHENE

ALKALI SALTS

*NaOH	K ₂ CO ₃
*Ca(OH) ₂	CaO
*Na ₂ CO ₃	NaSO ₃
PROPYLENE CARBONATE	

AMINES

MONOETHANOLAMINE	METHYL DIETHANOLAMINE
DIETHANOLAMINE	DI-ISOPROPOPANOL AMINE

*HIGHEST PRIORITY

Figure III-9. Additional Components Required in the SSI-PROCESS Data Base

- (2) Add the components listed in Figure III-9 to the component data base. The electrolyte components are required for three phase flash calculations. The alkali salts are used in acid gas removal and SO_2 scrubbing. The amines are used as adsorbents in hydrogen sulfide removal.
- (3) Add a capability to solve for multicomponent reaction equilibrium. This is required to solve for reaction products in methanation, shift and other reactions.
- (4) Add a math logic capability. This is the ability to compute any algebraic function of any stream properties or unit operation parameters; perform logical tests based on the computed quantity; and modify any stream property or unit operations parameter based on the outcome of the test. This capability increases user flexibility to address unusual situations.

C. COAL GASIFICATION REACTOR MODELS

1. Overview

Realistic gasifier models that accurately predict yields are a useful tool in integrating the gasifier into the overall design and planning for a coal gasification plant. The need to consider the fluid flows occurring in the gasifier, coupled with analyses of the thermodynamics and stoichiometry of the myriad of component substances and their interactions, contribute to the complexity of the problem of developing a useful gasifier model.

In the next section the three major types of gasifiers are discussed. This is followed by a description of models that were investigated by BDM. Concluding this section are findings and recommendations on currently available gasifier models.

2. Types of Coal Gasifier Reactors

This section describes the three major types of coal gasifier reactors and some of the phenomena that must be modelled accurately to predict gasifier yields.

THE BDM CORPORATION

Coal is a highly complex and variable substance. In addition to varying proportions of carbon, hydrogen, oxygen, sulfur, and nitrogen, coal also contains large amount of silica and alumina, plus traces of many other elements. The presence of this large number of varying substances contribute to the difficulty in gasifier modeling.

Three major chemical processes occurring in all gasifiers are devolatilization, gasification, and combustion. Devolatilization produces methane and other combustible gases from the incoming coal. Gasification is the partial oxidation of the resulting char. It is endothermic and produces as major products the combustible gases carbon monoxide and hydrogen. The combustion reactions continue the oxidation to completion. Since they are exothermic, they supply the needed energy for the gasification reactions. The major products of combustion are carbon dioxide and water.

The product gas from a gasifier is divided into three classes based upon the heating value of the gas. Low - BTU gas has heating values in the range of 100 to 200 BTU/scf. Medium or intermediate - BTU gas is in the range of 200 to 500 BTU/scf, and high - BTU gas or substitute natural gas (SNG) has a heating value greater than 900 BTU/scf. In general, low - BTU gas is produced from coal, air, and steam; medium - BTU gas is produced from coals, oxygen, and steam; and high - BTU gas is produced by upgrading medium - BTU gas via catalytic conversion and methanation.

The three commonly used gasifiers are the fixed, fluidized, and entrained bed type. In a fixed bed gasifier crushed coal (3-50mm) is fed into the top of the gasifier and gravitates downward as it devolatilizes and then gasifies until it comes to rest on a grate at the bottom. The oxidant (air or oxygen) injected from below the grate sustains the combustion which occurs at the bottom. Typically, large amounts of coolant steam are also injected to keep the temperature in the lower part of the gasifier (combustion zone) below 2100°F, a typical ash fusion point. Above the combustion zone, the temperature gradually falls to about 1400°F in the gasification zone. Near the top of the bed the gasification reactions

THE BDM CORPORATION

cease and devolatilization of the fresh coal falling into the bed occurs at 600-1000°F. Typical of fixed bed reactors in the atmospheric hinge.

In a fluidized bed gasifier the coal is more finely ground (less than 8mm), and the oxidant flows up at a velocity slightly higher than that required to merely support the particles. A turbulent fluid medium of coal and gas results in which a thorough mixing of solids and gases is achieved, producing nearly isothermal condition in the reactor. The temperature is controlled to be between 1600° and 2100°F. The coal throughout in a fluidized bed gasifier is higher than that for a fixed bed because the uniform temperature and smaller particle size lead to higher reaction rate. However, necessary processing of caking coal and post-gasification treatment of removed ash containing unreacted complications to the overall system that must be taken into account in evaluating such a system for commercial use. A fluidized bed reactor process dating back to the 1920's is the Winkler.

In the entrained system there is no bed. Very small (less than .1mm) coal particles in a coal-water slurry are entrained in a gas flow together in a concurrent stream. Each bit of coal is therefore exposed only to the gas that surrounds it, but thorough reactions are promoted by very high temperature, 2400-2700°F. There are several advantages to this system, namely:

- (1) It is simple;
- (2) Coal particles are not in contact with each other so that there is no sticking;
- (3) High temperatures and small particles lead to high reaction rates which permit a high coal throughput.

An example of this type of gasifier is the Texaco system.

3. Available Gasifier Models

This section presents summaries on coal gasifier simulation models investigated by BDM. The available simulations and the extent to which they have been validated are summarized in Figure III-10.

MODEL/DEVELOPER	TYPE OF GASIFIER	VALIDATED ON BENCH MODELS	VALIDATED ON PILOT OR COMMERCIAL SYSTEMS
1. COAL GASIFICATION SIMULATOR/ SSS	FLUIDIZED BED ENTRAINED FLOW	NO	NO
2. DYNAMICALLY MODELLED COAL GASIFICATION SIMULATOR/ SCHEISSER	ENTRAINED FLOW	NO	NO
3. FIXED BED COAL GASIFICATION/ T. F. EDGAR	FIXED BED	NO	YES
4. FLUIDIZED BED GASIFIER/ H. S. CORAM	FLUIDIZED BED	YES	NO
5. GASIFIER MODELLING/C. Y. WIN	ALL	NO	NO
6. MODELLING AND ANALYSIS OF MOVING BED COAL GASIFIERS/ EPRI	MOVING BED	--	YES
7. IDICOG AND PCGC-1/P. SMITH	ENTRAINED FLOW	YES	NO
8. NASA COMBUSTION MODELS/NASA	ENTRAINED FLOW	--	YES ⁽¹⁾

(1) EXTENSIVE VALIDATION ON ROCKET ENGINES -- ONLY LIMITED VALIDATION ON GASIFIERS

Figure III-10. Nonproprietary Coal Gasifier Reactor Models

THE BDM CORPORATION

a. Coal Gasification Simulator by Systems

This model contains simulators for fluidized bed and entrained flow coal gasifiers. The fluidized bed has a two phase representation. Given a prescription for the composition of the materials and their chemical interactions, the model predicts the hydrodynamics and chemical behavior by simultaneously solving mass, momentum, and energy balances for gas and solids in the reactors. The models have not yet been validated against experimental data. Data for validation is expected from two fluidized bed plants developed by DOE and the entrained flow gasification plant by Texaco.

b. Dynamically Modeled Coal Gasification Simulator

The dynamically modeled coal gasification simulator by Dr. Schiesse at Lehigh University is a one-dimensional entrained flow gasifier model. Dynamically modeled, it evolves in time. Perfect mixing is assumed. There has been not experimental validation.

c. Fixed Bed Coal Gasification Simulator

The fixed bed coal gasification simulator by T. F. Edgar at the University of Texas is a one-dimensional fixed bed gasifier model. It does not handle turbulent flow. It can handle 8-10 components in a process. Giving only limited information on material and wastes from inputting actual data for fixed gasifiers, one would have to specify heat losses from the reactor itself in addition to flow being considered by the model. One major difficulty in using this model, or any gasifier model, is the inability to describe the coal sufficiently. A validation is performed by trying to match model results using reported data from a variety of fixed bed projects.

4. Fluidized Bed Gasifier by H. S. Coram

The fluidized bed gasifier by H. S. Coram at Lehigh University models the kinetics of coal reactions in a fluidized bed gasifier. The dynamic behavior is modeled. A model for a Winkler gasifier has been developed. The model has been validated for a 6"-8" diameter gasifier, but is not readily applicable to a prototype plant.

THE BDM CORPORATION

5. General Gasifier Modeling by C. Y. Win

C. Y. Win of the University of West Virginia has developed general models for various types of coal gasifiers in terms of the internal reactions. There has been no model validation.

6. Modeling and Analysis of Moving Bed Coal Gasifiers

The modeling and analysis of moving bed coal gasifiers by EPRI is a steady-state model of moving bed coal gasifiers based on kinetics and transport rate processes, thermodynamic relations, and mass and energy balances. The principle investigators are H. Yoon, J. Wei, and M. M. Dunn, of the University of Delaware. A modified model is applied to a pressurized slagging reactor. Validation is performed by comparison with published plant data for the Lurgi gasifier. Results of the model applied to a pressurized slagging reactor are compared with data from a pilot scale experimental reactor.

7. 1DICOG and PCGC-1 by F. P. Smith

The 1DICOG and PCGC-1 by F. P. Smith of Brigham Young University are one-dimensional entrained flow gasifier models. Plug flow is assumed. PCGC-1 is being extended to a two-dimensional model (PCGC-2) to handle general turbulent flow in the radial dimension. The models are validated from measurements of lab scale devices developed at BYU. 1DICOG has been applied at Foster Wheeler, and although good agreement is reported for "one-dimensional" reactors, it gives poor agreement for turbulent reactors.

8. NASA Combustion Materials

NASA has developed several combustion models for the study of combustion in rocket engines, including both one-dimensional and two-dimensional versions. Preliminary simulations have been conducted with the one-dimensional model and appear to compare favorably with some of Texaco's test results with eastern coal. Further simulations and test comparisons are planned.

9. Findings and Recommendations

Based on the study of available gasifier models, non-proprietary currently available models are too rudimentary to be of value as design tools. Specific findings are:

- (1) Models are usually one-dimensional and most models do not have the ability to handle turbulent flow

THE BDM CORPORATION

- (2) Models are general, lacking necessary detail to model a real gasifier
- (3) Only two models have been even partially validated on a pilot or commercial plant
- (4) Investigators all report that results are very sensitive to the specified coal chemical composition, which is usually not well known in practice.

Based on these finds, the following recommendations are made:

- (1) Only validated models should be used
- (2) The models should be used only for reasonability checks on vendor-specified yields, not as a design basis

D. Detailed Approach and Findings - Economic Methods and Models

1. Introduction and Overview

The purpose of this task is to identify methods and models required for the economic analysis of coal-based synthetic fuels complexes. In this section the requirements for economic analysis are first delineated. A survey of available methods and models is then provided. Criteria for evaluation and recommendation of selected methods and models follows. Specific recommendations for general guidelines to economic evaluation, cost estimation models and techniques, and financial models are then given. Guidelines for Economic Evaluation of Coal Conversion Processes, prepared by The Engineering Society Committee on Energy served as a key criteria for evaluating the available methods and models. The ESCOE guidelines are also recommended for use as a general guide to any economic analysis of a coal conversion process. A general outline of the Guidelines is provided to serve as a context for the other recommendations of specific models and manual techniques. Finally, a brief discussion of problems encountered in the cost estimation of new processes is presented.

2. Requirements for Economic Models and Techniques

The economic analysis required to support coal-based synthetic fuels complex studies can be performed using two types of models or techniques: cost estimation and financial evaluation (see Figure III-11). An

THE BDM CORPORATION

OBJECTIVES

- ESTABLISH ECONOMIC VIABILITY OF COAL CONVERSION PROCESS PLANT
- COMPARE COMPETING TECHNOLOGIES
- EVALUATE MARKET UNCERTAINTIES AND ALTERNATIVE FINANCING ARRANGEMENTS

METHODS REQUIRED ECONOMIC ANALYSIS

- CAPITAL AND OPERATING COST ESTIMATION
- FINANCIAL EVALUATION

Figure III-11. Requirements for Economic Analysis of a Coal-Based Synthetic Fuels Complex

THE BDM CORPORATION

estimate of the costs of constructing and operating a process plant is the basis of all other economic analyses. Models or manual techniques are required for accurately estimating both capital costs and operating costs at various stages of design and with different amounts of information. Financial models utilize these cost estimates in combination with market assumptions to assess the economic viability of a process, and to compare competing technologies. Financial models typically use a schedule of projected costs and production to build a projection of cash flow through the planned process plant, and discount that future flow of cash to reveal present value. Model outputs desired may include minimum economic product prices, the internal rate of return of the plant, the return on investment, and the operating break-even point. The financial model is also the basis for performance of sensitivity analyses to evaluate market uncertainties, and alternative financing arrangements.

3. Available Models and Techniques

Methods surveyed by BDM can be grouped into three categories: general guidelines, cost estimation methods, and financial analysis methods. (See Figure III-12.) General guidelines and considerations include sources which provide an overview of how to perform an economic evaluation.

Cost estimation techniques include both manual techniques and automated computer models. Automated models are divided into several groupings. A number of programs are available which estimate total plant costs based on combinations of historical data bases and cost factors. There are also a number of smaller programs designed specifically for individual components of the total plant. One program, CØST, combines the capability of supplying current labor and equipment costs with the capability to estimate total plant costs without using factors.

Financial models have also been grouped into several categories. The largest group contains models which utilize a standard cash flow model yielding several of a number of possible outputs including net present value, rate of return, net cash to equity, and break-even points. They

THE BDM CORPORATION

GENERAL GUIDELINES AND CONSIDERATIONS

- GUIDELINES FOR ECONOMIC EVALUATION OF COAL CONVERSION PROCESSES, ESCOE
- REVIEW OF COST ESTIMATION IN NEW TECHNOLOGIES: IMPLICATIONS FOR ENERGY PROCESS PLANTS, AND

COST ESTIMATION TECHNIQUES

MANUAL TECHNIQUES

- GUTHRIE MODULAR APPROACH
- RICHARDSON RAPID SYSTEM

TOTAL PLANT COST MODELS USING FACTORS

- CHEMICAL ENGINEERING ECONOMIC PEAKAGE
- COST (DATA BASE FIVE FACTORS)
- ECONOMIST (FACTORS PCOST)
- PEPCOST
- E-301 PROGRAM
- PROVES

COMPONENT COST ESTIMATES

- PRESSURE VESSEL COST EST.
- PROGRAM 5066 (SHELL & TUBE HEAT EXCHANGER)
- WASTEWATER TREATMENT PLANT COST ESTIMATING
- WORK SAMPLING PROGRAM
- HEAT EXCHANGER PRICING PROGRAM

CURRENT DATA BASE FOR EQUIPMENT QUOTES

- PDQ\$

TOTAL PLANT COST USING CURRENT VENDOR QUOTE DATA BASE AND NO FACTORS

- COST

FINANCIAL MODELS

GENERAL CASH FLOW

- PCOST
- CASH FLOW
- CASH FLOW ANALYSIS
- CASH FLOW FORECAST
- DISCOUNTED CASH FLOW CALCULATIONS
- DISCOUNTED RATE OF RETURN ON INVESTMENT
- ECONOMIC EVALUATION OF PROCESS OPERATING AND CAPITAL COSTS
- PRV
- PROFIT (INTERACTIVE)
- ROCKETDYNE MFS-19040
- PROVES

SPECIALIZED ROUTINES

- ECONOMIC EVALUATION OF WATER SUPPLY AND DISPOSAL
- CHEMICAL PROCESS SCREENING PROGRAM

PROBABILISTIC MODELS FOR UNCERTAINTY

- PLANNING AND ANALYSIS IN UNCERTAIN SITUATIONS
- PROFITABILITY ESTIMATION USING PROBABILISTIC DATA INPUTS

Figure III-12. Available Economic Models and Methodologies

THE BDM CORPORATION

differ in their outputs, and the flexibility of conditions they allow the user. A second group is composed of smaller programs developed for more specialized purposes. The third group combines the traditional cash flow analysis with a probabilistic component to allow for uncertainty.

4. Criteria for Selection of Plant Cost Estimation Methods and Models

Five criteria were used to select cost estimation models and techniques. (See Figure III-13.) Consistency with the generally accepted and respected practices of the process design industry was a key criterion in the evaluation of the methods surveyed. The Guidelines for Economic Evaluation of Coal Conversion Processes prepared by ESCOE were designed to represent a standard for analysis by the process design industry. As such, consistency or usefulness within the framework of the ESCOE Guidelines was used as a means of evaluating other models and techniques. A second report, A Review of Cost Estimation on New Technologies, by the Rand Corporation indicates limitations and potential for incorrect usage of various techniques. Both Guidelines and the Rand Review served as a backdrop to selection of appropriate models and techniques.

The models surveyed were also assessed in terms of the currency of their data base, their applicability to estimates required at the various stages of process design (from order of magnitude to budget estimates), and the amount of support provided by the vendor supplying the model. The ability of the model or manual technique to estimate total plant costs was also considered. There are many programs available for cost estimation of particular components, but these are by definition of limited applicability.

5. Findings and Recommendations

a. Summary of Findings and Recommendations

Recommendations have been made here of general guidelines to be followed in economic evaluation of a process plant, of specific cost estimation models and manual techniques, and of financial models (see Figure III-14). Guidelines For Economic Evaluation Of Coal Conversion Processes, prepared by ESCOE are recommended for use as a general guide to

THE BDM CORPORATION

- CONSISTENT WITH ESCOE GUIDELINES
- ACTIVE AND WIDESPREAD USE BY PROCESS DESIGN INDUSTRY
- ADEQUATE VENDOR SUPPORT
- APPLICABILITY TO ALL STAGES OF PROCESS DESIGN
- CURRENT DATA BASE

Figure III-13. Criteria for Selection of Plant Cost Estimation Methods and Models

THE BDM CORPORATION

- ADHERENCE TO ESCOE GUIDELINES FOR COST ESTIMATION AND EVALUATION
- COST ESTIMATION TECHNIQUES
 - RICHARDSON'S RAPID SYSTEM (MANUAL)
 - TRIAL OF AUTOMATED MODEL COST
 - EXPERIENCED ESTIMATOR IS ESSENTIAL WHEN USING MANUAL OR AUTOMATED TECHNIQUE
- FINANCIAL ANALYSIS
 - COMPARABLE MODELS WIDESPREAD
 - CONSTRUCTION OF IN-HOUSE MODEL TO IMPLEMENT ESCOE METHODOLOGY

Figure III-14. Findings and Recommendations

THE BDM CORPORATION

economic evaluation. They should be adhered to in all economic evaluations to allow accurate comparisons of various technologies, and to serve as a framework for the appropriate use of various models and techniques for cost estimation and financial projections. For cost estimation, it was found that manual systems predominate in the process design industry. Two systems, commonly referred to as the Richardson Rapid System, and the Guthrie method, are widely acknowledged and utilized cost estimation techniques. The Richardson Rapid System is recommended for manual cost estimation. An automated cost estimation model, CØST, marketed by the ICARUS Corporation, is recommended for further examination. Several financial models were reviewed and found comparable. However, it is recommended that the user develop a financial model to ensure that it exactly reflects the user's unique requirements.

b. Background to Findings and Recommendations

Economic methods and models have been selected to fulfill several potential objectives. Evaluation of economic viability of specific coal conversion process plants may be required; competing technologies may require comparison, and the effects of market uncertainties and alternative financing arrangements for a specific project may need evaluation. Two analytic methods are required to fulfill these objectives. Methods are needed to estimate capital and operating costs of a process, and methods of financial analysis are required to utilize these cost estimates and combine them with market assumptions to evaluate financial performance.

BDM has surveyed available automated models and manual techniques for cost estimation and financial analysis. Several criteria were used to evaluate the usefulness of these models and techniques to NASA. From this evaluation, several recommendations have been made. Guidelines for Economic Evaluation of Coal Conversion Processes, prepared by the Engineering Society Committee on Energy (ESCOE) were selected as representative of accepted practice by the process design industry. As such, consistency with the ESCOE guidelines was a key criteria in the evaluation of model and manual methods. The use of these guidelines as a

general guide to the appropriate use of both cost estimation and financial analysis is strongly recommended. Major considerations from these guidelines are outlined in the next section. Recommendations of specific automated models and manual methods for cost estimation and financial analysis follow below.

c. Cost Estimation Models and Manual Techniques

Manual techniques were found to predominate among cost estimation methods. Two of the most widely used manual techniques for cost estimation are the Guthrie and Richardson methods. The Guthrie method is based on historic data of cost patterns and relationships derived from more than 50 refineries and processing plants. Cost of equipment is derived by specifying size, type of material, duty, etc., and using "appropriate" multipliers to estimate field materials and installation costs.

The Richardson method (Figure III-15) follows the same general approach as Guthrie's method, but includes much more specificity in sub-accounts. It also utilizes current prices. Both of these considerations increase its accuracy, and it is therefore recommended. One disadvantage, however, is that the level of detail it requires may mean more estimating time is necessary.

One automated system, CØST, marketed by the ICARUS Corporation, is recommended for evaluation (Figure III-16). The model relies on an extensive material, equipment, and regional labor cost data base that is updated semi-annually. It has a claimed reliability of +15% to -0% projection of actual field construction costs. The expense of CØST appears comparable to manual techniques. Its attraction is that it provides costs based on specified equipment, with consistent methodology, and thoroughly documented assumptions and data. No factors are used. It also results in substantial time savings as it provides full plant estimates within days as contrasted to the month or more required for manual techniques.

It is important to recognize that no technique is fully automatic or routine. The effective use of CØST or the manual techniques depends significantly on the knowledge, experience, and skill of the estimator.

THE BDM CORPORATION

- EXTENSIVE CURRENT PRICE DATA BASE TO ESTIMATE PURCHASED EQUIPMENT COSTS GIVEN SIZE, FUNCTION, AND MATERIALS
- UTILIZES FACTORS TO ESTIMATE ADDITIONAL COSTS OF PIPING, WIRING, INSTRUMENTATION, INSULATION, AND PAINTING
- DATA BASE INCLUDES CURRENT PRICES BY LOCATION
- PROJECT CONTINGENCY APPLIED TO SUM OF ALL EQUIPMENT COSTS INCLUDING PURCHASE COST, INSTALLATION COSTS, AND DIRECT COSTS
- REQUIRES DETAILED CONCEPTUAL PLANT DESIGNS AND SCHEDULES

Figure III-15. Features of Richardson Rapid System
(Manual Cost Estimation)

THE BDM CORPORATION

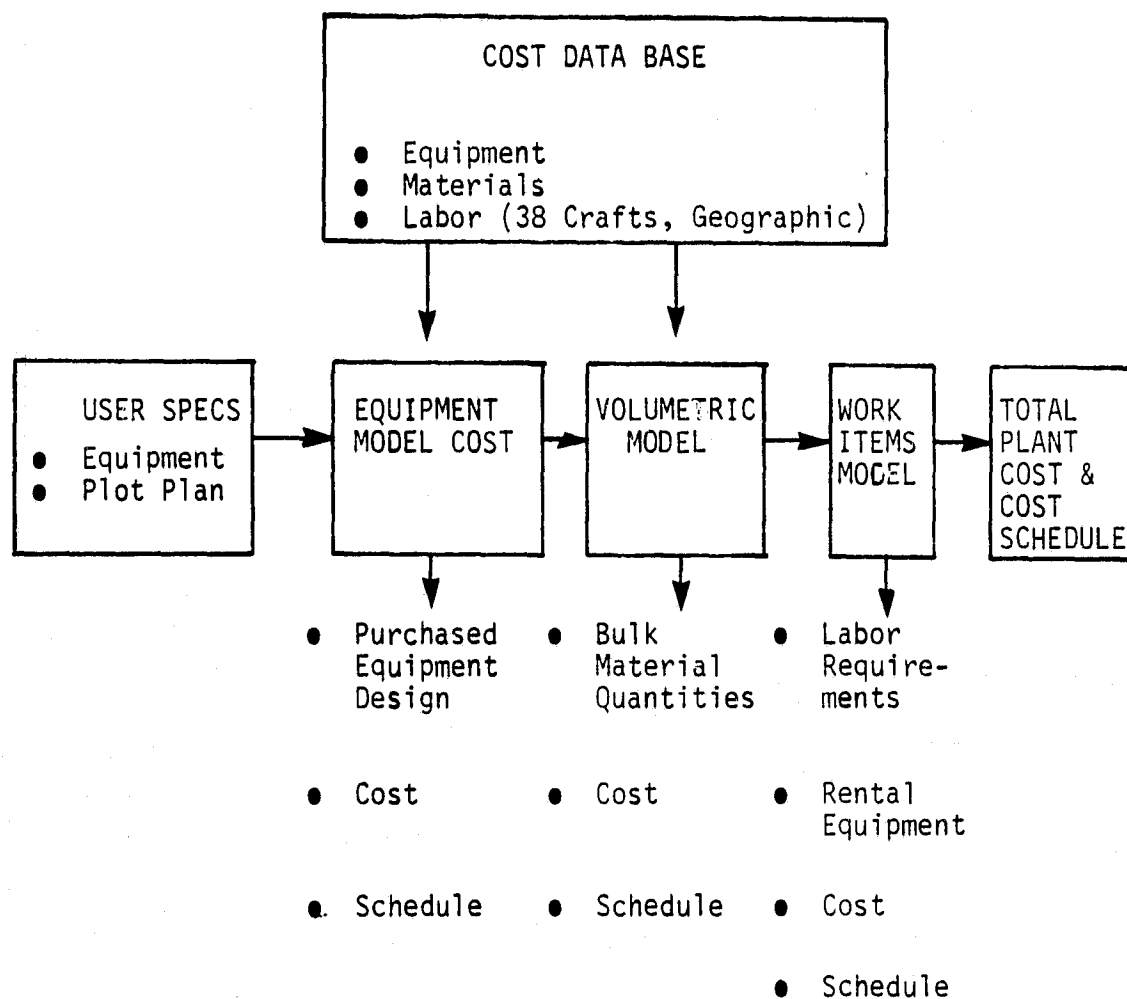


Figure III-16. Overview of ICARUS COST System for Plant Cost Estimation

THE BDM CORPORATION

d. Financial Models

Several models of comparable capability are widely available for financial evaluation. Most are based upon a cash flow account and yield a number of different quotients including cost of product produced, the overall rate of return, and the return on equity.

Due to the low cost and benefits of constructing a model reflecting the exact requirements of outputs required by the user, it is recommended that the user construct an in-house model based on the ESCOE guidelines.

6. Overview of the ESCOE Guidelines

a. Introduction

The Guidelines for Economic Evaluation of Coal Conversion Processes, prepared by ESCOE, were developed to serve as a standard for the evaluation of coal conversion processes. Its use is recommended to encourage systematic evaluation, appropriate use of specific models and techniques, and valid comparisons between alternative projects. Considerations from the Guidelines are outlined here. A full work breakdown outline for economic evaluation from the Guidelines are included in an attachment to this chapter.

b. Collecting Necessary Inputs for Performance of Economic Evaluation

Before an economic evaluation of a process can be conducted the necessary inputs to that evaluation must be prepared. These inputs include:

- (1) An understanding of the stage of technical development the process is (Figure III-17) in
- (2) An understanding of the type of cost estimate required for the purpose at hand (see Figure III-18)
- (3) Preparation of schedules for construction, production, and manpower
- (4) Establishing the scope of the project; including considerations of plant size, level of operation, potential sites, feedstocks, products, expected plant life, thermal efficiencies, support facilities and utilities required, manpower, etc.

STAGE	PURPOSE	CHARACTERISTICS
Concept	The purpose of the concept stage is to provide a brief but complete description of an energy project and the essential processes so that initial judgments can be made for planning.	The concept study includes study of process reactions, materials and engineering requirements. Elementary flow diagrams and plans and results of laboratory tests and/or "bench" experimental work may have been used to establish scientific feasibility of the processes involved.
Process Development Unit (PDU)	The purpose of a PDU is to establish the basic technical feasibility of the process; acquire basic physical, chemical and engineering data needed to evaluate the process; and develop the design data necessary to allow further scale-up to a larger stage if feasible.	PDU's incorporate the results of laboratory "bench-scale" experimental work on key process steps. They form an integrated process unit sized to process the minimum amount of new material necessary to test the feasibility of the process. PDU's generally operate continuously and are a component of or contained in an existing facility (e.g., laboratory or plant).
Pilot Plant	The purpose of a pilot plant is to establish the integrated process feasibility by combining commercial type (not commercial size) components into a small model plant to test and evaluate the critical parameters of scale-up, and to acquire engineering data needed to assess economic feasibility and design a larger near-commercial-size plant.	Pilot plants are the first scale-up facility to produce enough endproduct to permit product testing and refinement. They are generally limited to three years or less of operating life and are subject to continuing and significant modifications. Pilot plants should provide sufficient data about operations for cost projections and development of commercial demonstrations.
Demonstration Plant	The purpose of a demonstration plant is to demonstrate and validate economic, environmental, and productive capacity of a near-commercial-size plant by integrating and operating a single modular unit using commercial-sized components.	Demonstration plants are still developmental in the sense that technological scale-up problems may occur and require engineering modification. They are planned to become part of a commercial plant and are used to demonstrate and verify those technologies not currently used commercially.
Commercial Demonstration Plant	The purpose of a commercial demonstration plant is to resolve commercial investment uncertainties by establishing the actual economic factors, environmental feasibility, socioeconomic impact, capital and resource requirements, constraints and product markets for currently available as well as newly introduced synthetic fuel products and encourage creation of a viable industry using these technologies	Commercial demonstration plants do not constitute R&D work. These plants combine modular production units using commercial scale equipment and conditions to produce commercially significant quantities of commercial grade product.

REPRODUCIBILITY OF THIS ORIGINAL PAGE IS POOR

*Adapted from DOE/ET-0013 (78), pp. 457-9, see reference list.

(Excerpt from Guidelines For Economic Evaluation Of Coal Conversion Processes, ESCOE, April 1979, p. 7.)

Figure III-17. Technical Development of Process Plants
Classification of Project Stages*

CLASS OF ESTIMATES	ORDER OF MAGNITUDE, CLASS 1	PRELIMINARY (BUDGET) CLASS 2	DEFINITIVE, CLASS 3
Purpose	For management decisions on feasibility for further study.	For research and development planning and decisions for establishing technology development priorities.	For appropriation of funds for a project or for a construction contract price.
Quality (Error Range)	-30% to +50%	-15% to +30%	-5% to +15%
Information Available	<p>The general type, quantity, and quality of main product(s) and supply(s).</p> <p>Individual process steps and major equipment items.</p> <p>Basic flow diagram.</p> <p>Location may be regional or a general site area.</p>	<p>Type, quantity, and quality of products and feedstock.</p> <p>Preliminary flow charts, plot plans, layouts, heat and material balance.</p> <p>Equipment types, sizes, and materials of construction.</p> <p>Building, storage, auxiliary requirements are known.</p> <p>Location may not be specific but general site conditions are known.</p>	<p>Specified type, quantity and quality of products and feed materials.</p> <p>Defined unit production capacities.</p> <p>Complete list of specified equipment.</p> <p>Engineered heat and material balance and complete flow diagram.</p> <p>Defined utility, storage, services, and handling requirements.</p> <p>Preliminary to complete design drawings showing special feature.</p> <p>Specific site conditions known.</p>
Capital Cost Estimating Procedures	<p>Cost-capacity curves or formulas.</p> <p>Ratio extrapolation for known equipment.</p> <p>Buildings at $\\$/ft^2$ rates.</p> <p>Percentage additions for indirect costs.</p> <p>Adjustment for time, size, and location.</p>	<p>Estimate individual equipment items using $\\$/capacity$, pressure, $\\$/lb.$ of steel, etc.</p> <p>Increase total equipment cost for the total process cost by ratio.</p> <p>Building at $\\$/ft^2$ or parametric estimates.</p> <p>Inventory, start-up, working capital as percent of direct capital or based on production capacity.</p> <p>Adjustment for time, size and location.</p>	<p>Preliminary to final quotes on equipment and labor costs.</p> <p>Rough to detailed quantity take-off and labor estimates.</p> <p>Quantity or activity estimate for indirect costs.</p> <p>Adjustments for time, size and location.</p>
Operating Cost Estimating Procedures	<p>Percentage of capital cost.</p> <p>Cost-capacity curves or formula.</p> <p>Basic labor, materials and price extensions.</p>	<p>Estimate as percent of capital, size of plant, production rates.</p> <p>Estimated feed rate, production rates.</p> <p>Indirect costs as percent of capital cost or ratio of direct operating costs.</p>	<p>Detailed estimate of feedstock, supply and production rates.</p> <p>Breakout of maintenance and overhead by major departments.</p> <p>Adjustments for time and location.</p>

*Based on classes and information from AACE (see reference list)

(Excerpt from Guidelines For Economic Evaluation Of Coal Conversion Processes, ESCOE, April 1979, p. 8.)

Figure III-18. Classification of Cost Estimates

THE BDM CORPORATION

- (5) Collecting the inputs of the process design methodology which will specify the process flow diagrams, the heat and material balances, and the design of necessary equipment. It is especially important to document non-standard equipment requirements in terms of size, materials, and special features.

c. Cost Estimation

1) Capital Cost

Estimating capital costs for processes utilizing major untried components requires careful accounting for unknowns. The uses of rules of thumb, analogy, detailed manual procedures, and automated models to estimate the cost of untried equipment are all common. A breakdown of all costs to be considered in the capital cost is provided in Figure III-19. Particular attention should be paid to the estimates for process and project contingencies. The assigned values of process contingency should reflect the stage of technical development of the process and/or the quality or reliability of the data being used for design. In the absence of prior experience with the development of similar processes, Figure III-20 gives rule-of-thumb guidelines for assigning process contingency allowances.

<u>DEVELOPMENT STAGE FROM WHICH PROCESS DATA IS AVAILABLE</u>	<u>PROCESS CONTINGENCY AS PERCENT OF INSTALLED SECTION COST</u>
CONCEPT WITH BENCH-SCALE WORK	50%
PROCESS DEVELOPMENT UNIT	25%
PILOT PLANT	15%
DEMONSTRATION PLANT	10%
COMMERCIAL DEMONSTRATION PLANT	5%

Figure III-20. Rule-of-Thumb Process Contingencies

2) Operating Costs

The calculation of operating costs depends in part on the capital cost estimate for an accurate estimate of maintenance costs,

THE BDM CORPORATION

Capital Cost Items	Line Item Estimates	Totals
Land (1)		
Working Capital		
Subtotal (Non-depreciable items)	_____	

Total Installed Cost (2)		
This includes process contin- gencies which total \$ _____		
Initial Catalyst, Chemicals, Operating Supplies		
Start-up Costs		
Contractor Cost and Fee		
Owner's Cost		
Project Contingency		
Subtotal (Depreciable Plant Costs) (3)	_____	

TOTAL (Estimated Construction Costs) (4)		
<p>*All estimates in _____ year dollars (base year date).</p> <p>Notes: (1) Where cost of land is relatively small, it may be stated as less than "_____" percent of total and not reported as separate item.</p> <p>(2) Total installed cost to be further broken down into separate estimates for process blocks and offsite facilities, and reported separately. Show any process contingency.</p> <p>(3) To be used as Depreciable Plant Costs in Figure 8.1.</p> <p>(4) To be used as Estimated Construction Costs in Figure 8.1</p>		

(Excerpt from Guidelines For Economic Evaluation Of Coal Conversion Processes, ESCOE, April 1979, p. 26.)

Figure III-19. Capital Cost Summary

THE BDM CORPORATION

insurance, and any ad valorem taxes. A breakdown of operating cost sub-accounts is included in Figure III-21. Quantities of raw material inputs to be used during operation by the process are derived from the material balance calculations. Any catalyst and chemical requirements are derived from stated plant capacity. Unit costs for materials and labor can be derived from vendor quotes.

3) Scheduling of Costs

Not only do costs have to be calculated, their occurrence must be planned for and scheduled. The occurrence of capital costs are planned through a construction schedule. Such a schedule will likely follow a S-shaped curve of expenditures over time. It should also include a milestone chart identifying critical goals. Operating costs are scheduled with a production schedule. The production schedule should include provisions for downtime including scheduled maintenance and rehabilitation necessary for plant life.

4) Financial Analysis

The financial projection utilizes the schedules of estimated costs and assumptions concerning financing of a process to generate indices which can be used to measure the potential viability of a process, compare competing processes, and evaluate different financial arrangements for the financing of a process. The cash flow account is the basis for calculations in most methods. A summary of data to be utilized in the financial analysis is given in Figure III-22.

7. Problems in the Economic Evaluation of Coal Conversion Processes

a. Introduction

The Rand Review of Cost Estimation Methods in New Technologies demonstrates that "estimates of capital costs of pioneer energy process plants have been poor predictors of actual capital costs. Pre-design and early design estimates have routinely understated definitive design estimates or ultimate costs by more than 100%." This failure can be attributed to:

- (1) Endogenous uncertainty
- (2) Methodological problems

THE BDM CORPORATION

Cost Group	Estimate Base		Annual Cost*
	Unit	Quantity Price	
Feed Materials - Coal			
Feed Materials - Other			
Catalysts, Chemicals and Operating Supplies			
Utilities and Fuels			
Operating Labor			
Maintenance Labor Material			
Supervisory Labor			
Administration and Overhead			
Fringe Benefits			
Local Taxes and Insurance			
Royalties			
Waste Disposal			
TOTAL**			

* All estimates are in _____ year dollars (base year date).

** To be used as Annual Operating Costs for Base Year Estimates in Figure 8.1.

(Excerpt from Guidelines For Economic Evaluation Of Coal Conversion Processes, ESCOE, April 1979, p. 30.)

Figure III-21. Summary of Annual Operating Costs*

Sponsor (Private/Utility) _____			Analysis Parameters (cont.)		
Dollar Method (Then-current/Constant date) _____			Tax Rate and Schedules (4)		
Base Year Estimates			Effective Income Tax Rate _____		
Dollar Year for all Base Data _____			Federal Income Tax Rate _____		
Estimated Construction Costs (Fig. 5.1 total) _____			State/Local Income Tax Rate _____		
Depreciable Plant Costs (1) _____			Effective Investment Tax Credit Rate (ITC) _____		
Annual Operating Costs (Fig. 6.1 total) _____			ITC Claim Schedule (year, % of investment) _____		
Annual By-product Revenue (Fig. 7.2 total) _____			Income Tax Credit Treatment (5) _____		
Net: Operating Costs Less By-Products Revenue _____					
Major Product(s) Output (2) _____					
Analysis Parameters					
Schedules	Dates	Times, years	Base Data Adjusted to Start-up Date		
Construction	_____ to _____	_____	Total Capitalized Investment, TIC (\$) _____		
Operation	_____ to _____	_____	Depreciable Plant Investment (1) _____		
Retirement	_____ to _____	_____	Annual Operating Costs _____		
Construction Exp.			Annual By-product Revenue _____		
Rates (%/year) (3)			Net Annual Operating Cost (\$/year) _____		
Plant Start-up Rates (% Annual Production Rate)			Year of Adjusted Data _____		
Discount Rates (% per year)			Analysis Results		
Construction Loans			Major Products Price (\$/unit) (2) _____		
Debt Financing			Price Date (dollar year) _____		
Equity Financing			Overall Project Rate-of-Return (% per year) _____		
Overall Project Rate			Equity Investors' Rate-of-Return (% per year) _____		
			Payout Period (at zero interest) _____		
			Levelized Product Price _____		
Financial Structure			Notes: (1) Depreciable costs are total costs less nondepreciable items. See Figure 5.1 for items.		
Debt (% total)			(2) List each product to be priced.		
Equity (% total)			(3) Percentage of base year estimate.		
Escalation Rates (% per year)			(4) For income taxes and investment tax credits only.		
General Rate			(5) For cases where allowed deductible expenses exceed actual revenues.		
Depreciation Methods					
Tax Life (years)					
Method					

(Excerpt from Guidelines For Economic Evaluation Of Coal Conversion Processes, ESCOE, April 1979. p. 37.)

Figure III-22. Financial Analysis Data Summary

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

THE BDM CORPORATION

(3) Project organization

(4). Exogenous uncertainty.

The nature of each of these failures is briefly described below.

b. Endogenous Uncertainty

Changes in scope, design changes, insufficient product specification, and uncertainties related to scale-up can all have serious effects on the cost estimates.

c. Methodological Problems

There are several common methodological problems. The models and techniques chosen should be appropriate to the amount of detail available. Installation factors should be recognized as ranges based on historical data, and there should be more discriminating use of such factors. Attention should be concentrated on values commonly assumed such as the cost of money, effect of inflation on operating costs, and factors for piping and valves in field construction.

d. Project Organization

To the greatest extent possible the project should be coordinated by one individual. Hand-off of project responsibility from contractor to contractor is to be avoided. The importance of a single project manager and a few key personnel is great.

e. Exogenous Uncertainty

Both inflation and government regulation have greatly increased the degree of uncertainty in the business environment generally. These uncertainties affect coal conversion process plans as they do all other ventures.

THE BDM CORPORATION

ATTACHMENT A

WORK BREAKDOWN STRUCTURE FOR
COST ESTIMATION AND FINANCIAL
MANUAL EVALUATION, FROM
"GUIDELINES FOR ECONOMIC EVALUATION
OF COAL CONVERSION PROCESSES,
ESCOE, APRIL 1979, APPENDIX B"

GUIDELINES CHECKLIST

This appendix summarizes the reporting requirements for an economic evaluation report based on a preliminary cost estimate. The numerical listing of items refers to chapters or articles in the guideline and is provided as a convenience to the guideline user. Where information relating to a specific item is beyond the scope of the study or the information is not known, this should be so noted. For projects utilizing processes at the concept stage of development, information relating to many of the items will be necessarily incomplete. Conversely, for a Commercial Demonstration Project, it is expected that information pertaining to each item will be fully available and the list considered a minimum for reporting and evaluation purposes.

Article No.	Description
2.1	Purpose of the Report.
2.2	Scope of facilities in one paragraph, including nominal and operating capacity.
2.3	Classification of project's stage of technical development.
2.4	Classification of cost estimate and preparation effort.
2.5	Construction, production and manpower schedules.
3.0	Project Scope. Capacity Capacity Factor Site Conditions Plant Life Feedstock Characteristics Product Specifications Thermal Efficiency Process Schematic Offsite Facilities and Utilities Plant Expansion Allowances Plant Turndown and Alternate Feedstock Capabilities Plant Manpower
4.0	Plant Design - Document the following:
4.1	Process schematic diagrams
4.2	Process flow diagrams

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

THE BDM CORPORATION

4.3	Heat and material balances
4.4	<p>Equipment design and selection listing</p> <p>Non-standard equipment</p> <p>Materials (e.g., linings, special steels, etc.)</p> <p>Specifications (e.g., size, type, etc.)</p> <p>Number of spares and operating units</p> <p>Package plants</p> <p>Power generation or source</p> <p>Results of trade-off studies</p>
4.5	<p>Waste Management</p> <p>Document process design, types of control technologies, toxic streams and their special safety requirements for water, air and solid emissions.</p>
4.6	<p>Engineering assumptions</p> <p>Data sources</p> <p>Reaction design assumptions</p> <p>All input and output stream flow rates and compositions</p> <p>Temperature (and temperature profiles, if applicable)</p> <p>Pressure (and pressure profiles, if applicable)</p> <p>Residence times for each phase</p> <p>Catalyst life (if catalyst required)</p> <p>Catalyst circulation rates (if catalysts required)</p> <p>Catalyst makeup rates (if catalysts required)</p> <p>Percent conversion or conversion efficiency (define basis)</p> <p>Void volumes in packed beds</p> <p>Expanded bed densities in fluidized beds</p> <p>Recirculation rates in an ebullated bed</p> <p>Equilibrium temperature</p> <p>Space velocities</p> <p>Superficial velocities</p> <p>Compositions and flow rates of all bypassing, recycle or intermediate withdrawal streams</p> <p>Characterization of contaminants in the reactor effluent: particulates quantity and size distribution, tars (in the case of gasification, both quantity and composition), etc.</p> <p>Stream physical properties of intermediate streams</p> <p>Other assumptions used for equipment sizing</p>
5.1	<p>Method of estimating capital cost</p> <p>Installation factors for equipment</p> <p>Source of equipment cost and price information</p> <p>Price year and escalation factors</p>
5.2	<p>Process and offsite purchased equipment and installation costs</p> <p><u>A list of all major equipment and plant components.</u></p>

THE BDM CORPORATION

	Capital cost summary
	Land
	Total installed cost
	Paid-up royalties
	Initial catalyst chemicals and operating supplies
	Working capital
	Start-up cost
	Contractor's home office costs and fee
	Owner's cost
	Project contingency
	Process contingency
5.3	Construction schedule
5.4	Treatment of capital recovery
6.1	Source of price data for feed materials and other supplies
	Escalation and price index used
6.2	Estimates showing quantity and amount of the following annual costs:
	Feed materials - coal
	Feed materials - other
	Catalyst, chemicals, operating supplies
	Utilities and fuel
	Operating labor
	Maintenance
	Supervisory labor
	Administrative and general overhead
	Fringe benefits
	Local taxes and insurance
	Royalties
	Waste disposal
6.4	Production Schedule
7.1	Market study summary covering:
	Depth and scope of study
	Market location and types of available transportation
	Impact on transportation system capacity
	Impact of production size on market
7.2	For each by-product:
	Name
	Unit of sale
	Unadjusted market price, data source
	Adjusted price, point of sale
	Shipping and selling costs
	Price F.O.B., project site

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

THE BDM CORPORATION

7.5	For each by-product: Name Annual quantities Unit price Annual Revenue
8.1	Sponsor (type) Dollar method Base year date for all estimates Construction cost* Depreciable plant cost* Operating costs estimate* By-product revenues* Net expenses* *Also report adjusted estimates at start-up date Start-up date Construction schedule (dates) Operations period (dates) Retirement schedule (dates) Construction expenditure schedule, % each year Plant start-up efficiency, % each year Construction loan discount Debt interest rate Equity rate-of-return Overall project rate-of-return Debt as percentage of financing Equity as percentage of financing Escalation rate Depreciation method Depreciation period (tax life) Effective income tax rate Federal income tax rate State/local income tax rate Investment tax credit rate and schedule Income tax credit claim schedule Product price(s) and date of price Project rate-of-return realized Equity investors' rate-of-return realized Pay out period Levelized product price(s)
8.2	Year-by-year schedule of following: Capital investment Capital returns or losses on retirement Product revenues By-product revenues Feedstock expenses Other operating expenses Debt interest Debt retired Equity return and recovery

THE BDM CORPORATION

8.2 Year-by-year schedule of following: (cont.)

Income taxes
Depreciation

8.3 List of parameters and values for sensitivity analysis

8.4 For alternate case analysis - provide same information
as 8.1, 8.2 and 8.3

9.0 Comment on:

Recommended use of the report
Parameter values validity
New technologies and material reliability
Status of the reporter

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

THE BDM CORPORATION

CHAPTER IV TECHNOLOGY BASE ASSESSMENT

A. INTRODUCTION

The purpose of this particular phase of study was to investigate potential candidate coal gasification processes and to identify those which would most like be ready for commercial scale operation (1000 tpd. gasifiers) in a 1986-1990 time frame. Over 100 processes for production of low, medium or high BTU gas were initially studied and cataloged (see Appendix A). Criteria were then established to narrow this large list down to processes that are operating on a reasonable scale today in pilot or commercial plants. For the twenty-two (22) processes remaining after this rough screening, evaluation criteria related to large scale commercialization potential for the process were applied to these. Seven (7) were identified as processes that could possibly be implemented on a commercial scale (1000-2000 tons per day of coal per gasifier) by 1986-1990. These processes are:

- (1) Dry Bottom Lurgi
- (2) Winkler
- (3) Koppers-Totzek
- (4) BGC Slagging Lurgi
- (5) Texaco
- (6) Combustion Engineering
- (7) Shell-Koppers.

Each of those was then characterized as to product gas composition, by-products, gasifier efficiency, type of coal used, and several other factors. Data on the economics of the individual processes were not included in this table. This was primarily due to the lack of uniformity in the data, as well as to the failure of any of the sources to adhere to the guidelines for such evaluations as set forth by ESCOE. (Described in section E of Chapter III). Also included is a section evaluating the

THE BDM CORPORATION

quality of the data sources themselves to give an indication of the quality of data that is available in published reports.

B. GASIFIER PROCESSES INFORMATION CATALOG

To facilitate the process of providing information on viable coal gasification processes, a catalog of gasification processes was compiled, including a brief description of the process and type of gas produced, as well as information regarding the developer(s) and status. The catalog is broken up into two sections, one for "high" BTU and one for "low and medium" BTU processes. There are some 130 processes described, but this includes some duplication due to the nature of the production of high BTU gas (see Appendix A).

High BTU gas, or SNG (Synthetic Natural Gas) as it is often referred to, consists basically of methane (CH_4). The methane is generally produced from the reaction of hydrogen and carbon monoxide, which are the principal products from most gasifiers. Thus, the methanation step is actually a separate reaction stage that can be added to the end of many gasification processes.

C. TECHNOLOGY INFORMATION AND STATUS ASSESSMENT

As a preliminary step to selection of near-term potentially commercial processes, the large number of processes described in the catalog were screened to select processes that should be studied in more detail. The basic criteria used in this selection were that:

- (1) The process be in commercial operation, or
- (2) A pilot/demonstration plant, capable of processing 20 TPD (tons per day) or more of coal, be in operation and have exhibited extensions in the state-of-the-art technologies of proven gasification techniques were also included.

Twenty-two (22) gasification processes were put into this group. These processes were then characterized, as shown in matrix form in Figure

THE BDM CORPORATION

IV-1. There are thirteen (13) separate categories of data included plus a column for comments. The meaning of each of these is explained in detail as follows:

- (1) Process Name - Descriptive name of process.
- (2) Licenser/Developer - The companies that own the patent rights to the technology.
- (3) Product Gas - Type of gas produced - low, medium, or synthetic natural gas (SNG). Low-BTU gases are generally produced by direct gasification with air and steam, and thus contain considerable amounts of nitrogen. Such gases are primarily used for fuel. Medium BTU gases are used for fuel retrofit of existing power plants, combined cycle operation and chemical synthesis gases or precursors to SNG. They differ in composition from low-BTU gases principally in that they do not contain the diluent nitrogen; also they generally contain slightly more CO₂ due to the nature of the oxygen-rich reaction. This is either because the gasification is carried out with oxygen instead of air, or because the combustion step is physically separated from the gasification step so that the combustion and gasification products do not mix. In such cases, heat transfer between the combustion and gasification steps is accomplished by direct means such as a heat carrier.

When used for fuel gas or synthesis gas, the principal chemical values in low and medium-BTU gas are CO and H₂, whereas maximization of methane yield is desired when the gas is to be used as a precursor to SNG. Therefore, SNG processes generally maximize methane yield in the gasification to reduce the load on downstream shift and methanation units.

- (4) Type of Coal - The ranks of coals that have been processed at the pilot plant scale or larger; lignite (L), sub-bituminous (SB) and bituminous coking coals (B).
- (5) Bed Type - This term represents the general type of gasifier used. Types included fixed-bed, stirred-fixed bed, fluidized

Page intentionally left blank

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

PROCESS	LICENSOR/DEVELOPER	PRODUCT GAS	TYPE OF COAL	BED TYPE (1)	PRESSURE (2)	TURNDOWN RATIO PERCENT	PREPARATION	NUMBER OF REACTION ZONES	FEED METHOD	OVERALL COMPLEXITY
PRESSURIZED LURGI	LURGI (GERMANY)	LOW,MED,SNL	L,SB	FIXED BED, D.A.	M	25	CRUSH & SCREEN	THREE (ONE BED)	LOCK HOPPER	HIGH
WINKLER	DAVY POWERGAS (USA)	LOW,MED	L,SB	FLUIDIZED BED, D.A.	A	35	CRUSH & REMOVE BOTH FINES AND OVERSIZE PARTICLES	ONE (ONE BED)	SCREW FEEDER	MED
RUMMEL SLAG BATH	DR. C. OTTO & CO. (GERMANY)	LOW OR MED	NA	MOLTEN BATH, S.A.	A	NA	PULVERIZED	THREE (ONE BED)	NOZZLE	N.D.
KOPPERS-TOTZEK	KRUPP-KOPPERS (GERMANY)	MED	L,SB,B	ENTRAINED, S.A.	A	35	PULVERIZED	ONE (ONE BED)	SCREW FEEDER & NOZZLE	LOW
WELLMAN-GALUSHA	MCDOWELL-WELLMAN (USA)	LOW	SB,B	STIRRED-FIXED BED, D.A.	A	25	CRUSHED	THREE (ONE BED)	BIN-GRAVITY	MED
RILEY-MORGAN	RILEY STOKER CORP. (USA)	LOW	SB,B	STIRRED-FIXED BED, D.A.	A	20	CRUSHED	THREE (ONE BED)	BIN-GRAVITY	MED
WILPUTTE-PRODUCER	WILPUTTE CORP. (USA)	LOW	SB	STIRRED-FIXED BED, D.A.	A	20	CRUSHED	THREE (ONE BED)	BIN-GRAVITY	MED
WOODALL-DUCKHAM	WOODALL-DUCKHAM, LTD	LOW, MED	SB	FIXED BED, D.A.	A	25	CRUSHED	THREE WITH TWO GAS OFF-TAKES (ONE BED)	LOCKHOPPER	MED
STOIC	FOSTER-WHEELER (USA) ENERGY CORPORATION	LOW	SB	FIXED BED, D.A.	A	20-30	CRUSHED	THREE WITH TWO GAS OFF-TAKES (ONE BED)	DRUM FEEDER-GRAVITY	MED
WELLMAN-INCANDESCENT	APPLIED TECHNOLOGY CORPORATION (USA)	LOW	SB	FIXED BED, D.A.	A	20-30	CRUSHED	THREE, WITH TWO GAS OFF-TAKES (ONE BED)	DRUM FEEDER-GRAVITY	MED

FOOTNOTES:

(1) Type of Bottom for Bed

D.A. - Dry Bottom, Dry Ash
S.A. - Wet Bottom, Slagging Ash
A.A. - Dry Bottom, Agglomerated Ash

(2) Process Pressure

A - Atmospheric
L - ATM to 100 PSI
M - 100 to 500 PSI
H - over 500 PSI

(3) Plant Size/Type

C - Commercial Plant
P - Pilot Plant
D - Demonstration Plant
PR - Proposed Plant

EOLDOUT FRAME

Figure IV-1. Technology Status Assessment of Gasification Process

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

TURNDOWN RATIO PERCENT	PREPARATION	NUMBER OF REACTION ZONES	FEED METHOD	OVERALL COMPLEXITY	GASIFIER CAPACITY, TPD (3)	DEVELOPMENT STATUS, LBG	DEVELOPMENT STATUS, MBG and SNG	COMMENTS
25	CRUSH & SCREEN	THREE (ONE BED)	LOCK HOPPER	HIGH	800, C	COMMERCIAL	COMMERCIAL	
35	CRUSH & REMOVE BOTH FINES AND OVERSIZE PARTICLES	ONE (ONE BED)	SCREW FEEDER	MED	1,100, C	COMMERCIAL	COMMERCIAL	MAY BE ABLE TO USE CAKING COALS
NA	PULVERIZED	THREE (ONE BED)	NOZZLE	N.D.	N.D.	COMMERCIAL	NOT DETERMINED	NOT PRESENTLY IN USE
35	PULVERIZED	ONE (ONE BED)	SCREW FEEDER & NOZZLE	LOW	860, C	NOT DETERMINED	COMMERCIAL	
25	CRUSHED	THREE (ONE BED)	BIN-GRAVITY	MED	18-84, C	COMMERCIAL	NOT DETERMINED	
20	CRUSHED	THREE (ONE BED)	BIN-GRAVITY	MED	90, PR	COMMERCIAL	NOT DETERMINED	
20	CRUSHED	THREE (ONE BED)	BIN-GRAVITY	MED	30, C	COMMERCIAL	NOT DETERMINED	
25	CRUSHED	THREE WITH TWO GAS OFF-TAKES (ONE BED)	LOCKHOPPER	MED	48, C	COMMERCIAL	COMMERCIAL	
20-30	CRUSHED	THREE WITH TWO GAS OFF-TAKES (ONE BED)	DRUM FEEDER- GRAVITY	MED	108, C	COMMERCIAL	NOT DETERMINED	
20-30	CRUSHED	THREE, WITH TWO GAS OFF-TAKES (ONE BED)	DRUM FEEDER- GRAVITY	MED	103, C	COMMERCIAL	NOT DETERMINED	

2 ~~REIDOUT~~ FRAME

FOLDOUT FRAME

PROCESS	LICENSOR/DEVELOPER	PRODUCT GAS	TYPE OF COAL	BED TYPE (1)	PRESSURE (2)	TURNDOWN RATIO PERCENT	PREPARATION	NUMBER OF REACTION ZONES	FEED METHOD	OVERALL COMPLEXITY
BRITISH GAS CORPORATION SLAGGING LURGI	BRITISH GAS CORPORATION (U.K.) LURGI (GERMANY)	MED, SNG	L,SB,B	STIRRED-FIXED BED, S.A.	M	NA	CRUSHED	THREE (ONE BED)	LOCK HOPPER	HIGH
TEXACO	TEXACO DEVELOPMENT (USA) CORPORATION	LOW,MED,SNG	L,SB,B	ENTRAINED, S.A.	H	15	PULVERIZED	ONE (ONE BED)	WATER OR OIL SLURRY	LOW
SHELL-KOPPERS	S.I.P.M. (NETHERLANDS) KRUPP-KOPPERS (GERMANY)	LOW,MED,SNG	L,SB,B	ENTRAINED, S.A.	M	35	PULVERIZED	ONE (ONE BED)	WATER SLURRY	LOW
SAARBERG-OTTO	SAARBERG - DR. C. OTTO (GERMANY)	MED, SNG	NA	SLAG BATH, S.A.	M	30	PULVERIZED	THREE (ONE BED)	LOCK HOPPER WITH INJECTION NOZZLE	MED
COMBUSTION ENGINEERING	COMBUSTION ENGINEERING (USA)	LOW	SB,B	ENTRAINED, S.A.	A	40-60	PULVERIZED	TWO (ONE BED)	NOZZLE	LOW
COGAS	FMC CORPORATION (USA) B.C.U.R.A. (U.K.)	MED, SNG	B	PYROLYSIS AND FLUIDIZED BED, S.A.	PYROLYSIS, L GASIFIER, L	30-40	CRUSH AND REMOVE FINES AND OVERSIZED PARTICLES	FIVE (FIVE BEDS) (THREE PYROLYSIS ZONES, TWO GASIFICATION ZONES, THREE GAS OFF-TAKES)	HOPPER WITH A FLUIDIZED TRANSPORT SYSTEM	HIGH
ALLIS-CHALMERS (KILNGAS)	ALLIS-CHALMERS (USA)	LOW, MED	SB,B	ROTARY KILN, D.A.	L	10	SIZED	FOUR (ONE BED)	LOCK HOPPER	MED
HYGAS	INSTITUTE OF GAS TECHNOLOGY (USA)	SNG	L,SB,B	FLUIDIZED BED, A.A.	H	30-40	CRUSH AND REMOVE FINES AND OVERSIZED PARTICLES	FOUR (FOUR BEDS)	WATER OR OIL SLURRY	MED
BIGAS	BITUMINOUS COAL RESEARCH, INC. (USA)	SNG	SB,B	ENTRAINED AND VORTEX FLOW, S.A.	H	40-60	PULVERIZED	TWO (ONE BED)	WATER SLURRY	MED
METC	MORGANTOWN ENERGY TECHNOLOGY CENTER (USA)	LOW	SB,B	STIRRED-FIXED BED, D.A.	M	25	CRUSHED, SIZED	THREE (ONE BED)	LOCK HOPPER AND PRESSURIZED SCREW FEEDER	HIGH
SYNTHANE (PETC)	PITTSBURGH ENERGY TECHNOLOGY CENTER (USA)	MED, SNG	L,SB,B	FLUIDIZED BED, D.A.	H	40-60	CRUSHED	ONE (ONE BED)	LOCK HOPPER OR SLURRY FEEDER	MED
U-GAS	INSTITUTE OF GAS TECHNOLOGY (USA)	LOW, MED	SB,B	FLUIDIZED BED, A.A.	M	30-40	CRUSHED	ONE (ONE BED)	LOCK HOPPER	MED

FOOTNOTES:

(1) Type of Bottom for Bed

D.A. - Dry Bottom, Dry Ash

S.A. - Wet Bottom, Slagging Ash

A.A. - Dry Bottom, Agglomerated Ash

(2) Process Pressure

A - Atmospheric

L - ATM to 100 PSI

M - 100 to 500 PSI

H - over 500 PSI

(3) Plant Size/Type

C - Commercial Plant

P - Pilot Plant

D - Demonstration Plant

PR - Proposed Plant

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

Figure IV-1. Technology Status Assessment of Gasification Processes (Continued)

2

PREPARATION	NUMBER OF REACTION ZONES	FEED METHOD	OVERALL COMPLEXITY	GASIFIER CAPACITY, TPD (3)	DEVELOPMENT STATUS, LBG	DEVELOPMENT STATUS, MBG and SNG	COMMENTS
CRUSHED	THREE (ONE BED)	LOCK HOPPER	HIGH	400, D; 800-3800, PR	NOT DETERMINED	DEMONSTRATION	
PULVERIZED	ONE (ONE BED)	WATER OR OIL SLURRY	LOW	150, D; 1000, PR	PROPOSED	DEMONSTRATION	COMMERCIAL FOR HEAVY OIL GASIFICATION; 70 PLANTS
PULVERIZED	ONE (ONE BED)	WATER SLURRY	LOW	145-1000, PR	NOT DETERMINED	DEMONSTRATION	PRESSURIZED VERSION OF THE KOPPERS TOTZEK PROCESS
PULVERIZED	THREE (ONE BED)	LOCK HOPPER WITH INJECTION NOZZLE	MED	132, D	NOT DETERMINED	DEMONSTRATION	PRESSURIZED VERSION OF RUMMEL SLAG BATH PROCESS
PULVERIZED	TWO (ONE BED)	NOZZLE	LOW	120, D	PILOT PLANT	NOT APPLICABLE	
CRUSH AND REMOVE FINES AND OVERSIZED PARTICLES	FIVE (FIVE BEDS) (THREE PYROLYSIS ZONES, TWO GASIFICATION ZONES, THREE GAS OFF-TAKES)	HOPPER WITH A FLUIDIZED TRANSPORT SYSTEM	HIGH	36-50, P; 2200, PR	NOT APPLICABLE	PILOT	COMBINED LIQUIDS AND GAS PLANT: BASED ON COED LIQUID; LIQUIDS IN U.S., GASIFIER IN U.K.
SIZED	FOUR (ONE BED)	LOCK HOPPER	MED	820, PR	PILOT PLANT	NOT DETERMINED	DEMO PLANNED WITH EXTENSIVE UTILITY PARTICIPATION - PILOT PLANT RUN AT ATM. PRESSURE ONLY
CRUSH AND REMOVE FINES AND OVERSIZED PARTICLES	FOUR (FOUR BEDS)	WATER OR OIL SLURRY	MED	72, P	NOT APPLICABLE	PILOT PLANT	
PULVERIZED	TWO (ONE BED)	WATER SLURRY	MED	120, P	NOT APPLICABLE	PILOT PLANT	EXTENSIVE DAMAGE FROM RECENT FIRE
CRUSHED, SIZED	THREE (ONE BED)	LOCK HOPPER AND PRESSURIZED SCREW FEEDER	HIGH	20, D	DEMONSTRATION	NOT APPLICABLE	PRESSURIZED VERSION OF WELLMAN-GALUSHA PROCESS
CRUSHED	ONE (ONE BED)	LOCK HOPPER OR SLURRY FEEDER	MED	75, P	PDU OPERATION	PILOT PLANT	USES DEEP-BED INJECTION; FUNDING CANCELLED
CRUSHED	ONE (ONE BED)	LOCK HOPPER	MED	24 TPD, P 900, PR	PILOT	PILOT PLANT	

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

THE BDM CORPORATION

bed, entrained bed, or molten bath. Distinction is also made between the various ways in which ash or char is removed from the gasifier. Dry ash systems operate below the softening point of the ash. Agglomerating systems operate above the ash softening point to promote sticking-together of the ash particles with consequent particle growth. Slagging systems operate at temperatures that cause the ash to leave the gasifier in molten form.

- (6) Pressure - The operating pressure ranges within which the technology has operated. The following abbreviations are used: A-atmospheric, L-atmospheric to 100 psi, M-100 to 500 psi, H-greater than 500 psi.
- (7) Turndown Ratio - The minimum percent of design capacity for which the gasifier can sustain stable operations.
- (8) Preparation - The type of coal preparation required, e.g., crushing, pulverizing, etc.
- (9) Number of Reaction Zones - The number of separate reaction zones required by the technology. Examples of zone types are devolatilization, gasification, and combustion. Pretreatment of caking bituminous coals to destroy thin agglomerating tendencies is not included as a reaction zone.
- (10) Feed Method - The device or scheme by which coal is introduced into the gasifier. The feed method is generally determined by the operating pressure of the gasifier. Atmospheric pressure gasifiers use bins with gravity, screw, or drum feeders. Pneumatic transport of the coal into the gasifier by air or Oxygen plus steam is also practiced.

Low and medium-pressure gasifiers generally use pressurized lock-hoppers followed by screws or rotary feeders. An alternative to this method is to slurry the coal in either water or oil and pump it to gasifier pressure. This is generally avoided where possible because of energy penalties involved in vaporizing the slurry medium. In high-pressure gasifiers, the cost of compressing the lock gas and building suitable high-pressure solids

THE BDM CORPORATION

transfer equipment generally causes slurry feed systems to appear more attractive than dry feed (lockhopper) systems.

- (11) Overall Process Complexity - An estimate of the degree of complexity of construction and operation of the gasifier and its associated process equipment. The complexity was computed by assigning a numerical score to a series of factors by judgment, then aggregating the scores to a total for the process. The aggregate scores were then grouped into ranges representing low, medium, and high degrees of complexity.

The factors used in the complexity rating were as follows:

- (a) Difficulty of fines separation from raw gasifier product
- (b) Difficulty of tar and oil removal from raw gasifier product
- (c) Organic sulfur production and required removal
- (d) Difficulty of removal and treatment of water-soluble organics
- (e) Tar, oil, and water separation requirements
- (f) Requirements for mechanical agitation of gasifier bed material
- (g) Process control requirements for multi-stage or multi-zone reactors
- (h) Complexity or difficulty in coal preparation and feeding
- (i) Pretreatment required for caking coals
- (j) Difficulty of ash removal from process
- (k) Outside energy input requirements, primarily steam.

Processes which were anticipated to have little difficulty in addressing one of the above factors were assigned a score of zero for that factor. Those factors for which considerable difficulty was anticipated yielded a score of 2.0 for the process. The maximum score for any process was 22 points. Scores were grouped into ranges of low, medium, and high complexity as follows:

Low	0-8
Medium	9-13
High	Over 13.

THE BDM CORPORATION

- (12) Gasifier Capacity - The maximum number of tons per day of coal actually processed in the gasifier in its most advanced stage of actual development. In some cases, design bases are given for demonstration or commercial projects now under way.
- (13) Development Status - The most advanced stage of gasifier development; either pilot plant, demonstration, or commercial. A given stage may represent widely varying capacities among different processes. The distinction between "demonstration" and "commercial" was often not clear, particularly if only one plant had been built. However, the rationale used to distinguish the two was whether or not the process developer, so far as could be determined, intended to significantly improve or scale-up future gasifiers from the information gathered from the installation in question.

Different statuses were recognized for the two general types of raw product gases, low-BTU and medium-BTU/SNG. This was done to recognize the fact that many processes have been commercially applied to only one type of gas production, even though the licensor or developer claims that the process will work equally well on production of another type of gas.

D. SELECTION AND CHARACTERIZATION OF CANDIDATE PROCESSES

Seven processes were selected as having the potential for large scale (1000-2000 TPD per gasification) commercial operations in the 1986-1990 time frame. The selection criteria applied to the processes listed in Figure IV-1 were all directed toward that end. The criteria used in selecting these processes were as follows:

- (1) Minimum of a 100 TPD pilot/demonstration plant presently in operation.
 - (a) This keeps scale-up risk to the 1000 TPD plant to a reasonable level (10:1).

THE BDM CORPORATION

- (2) Pilot plant or demonstration plant runs of a reasonable duration. These are necessary to verify success of the pilot plant.
- (3) Funding: Must have at least partial financial backing of parties such as hardware or processes manufacturers. Processes funded entirely by parties such as A-E's, universities, Federal government, are not as credible as developers of commercially viable processes.
- (4) The completeness of the pilot plant is quite important. Ideally, all elements necessary for a full scale plant should be in the pilot; gasification system, solids handling system, acid gas clean-up system, etc. Also, the plant elements in the system should have been operated in a closed cycle mode to whatever extent possible.
- (5) There must be current ongoing development activity. To design and build a gasifier quickly, there must be a team of designers currently working with the technology.

Based on these criteria, the processes shown in Figure IV-2 were selected as candidate gasification systems for installation of a commercial unit (1000-2000 TPD Coal) in the 1986-1990 time frame. Presented for each process are specific details such as type of product gases, by-products, air/oxygen demands, coal characteristics, etc. The meaning of each of the columns presented in the table is explained below:

1. Feed Method

This describes the oxidant for the gasifier (oxygen or air) at atmospheric or elevated pressure and what type of bed is used (fixed, fluid or entrained).

2. Coal Type

This gives the type of coal that was used for the gasifier product composition shown in the table, along with BTU value of the coal. It does not give all the types of coal that might work in the system.

3. Product Gas Analysis

Gives the major raw gas components such as H_2 , CO , CO_2 , H_2S , etc., with the exception of ammonia (NH_3), if present. This analysis is

THE BDM CORPORATION

CORPORATION			PRODUCT		BY-PRODUCTS LBS./TON COAL	OXIDAND DEMAND LBS./LB. COAL	STEAM DEMAND LBS./LB. COAL	GASIFIER EFFICIENCY	DATA SOURCES
GASIFICATION	FEED METHOD	COAL TYPE	GAS ANALYSIS	PROCESS PRESSURE					
Volume									
LURGI, DRY BOTTOM	OXYGEN BLOWN	PITTSBURGH	H ₂	39.4	350-450 PSIG	LIQ. HYDRO- CARBONS = 130 PHENOLS = 8	0.6 (O ₂)	3.2	63 (1),(2), (3), 11
	PRESSURE: #8		CO	16.9					
	FIXED BED	14,900 BTU/ LB.	CH ₄	9.0					
			C _n H _m	0.8					
		(ASH & MOISTURE FREE BASIS)	H ₂ S+CO ₂	0.8					
			N ₂	1.6					
			CO ₂	31.5					
			285 BTU/SCF						
			65,000 SCF/TON COAL						
WINKLER	OXYGEN OR	LIGNITE,	H ₂	35.3	ATMOSPHERIC	LIQ. HYDRO- CARBONS = NIL PHENOLS = NIL AMMONIA = NIL SULFUR = 20 ASH = 15-30% CARBON	0.5 (O ₂)	0.7	75 (1),(2)
	AIR BLOWN	10,200 BTU/ ATMOSPHERIC; LB. (DRY)	CO	48.2					
			CH ₄	1.8					
	FLUIDIZED		C _n H _m	-					
	BED		H ₂ S+CO ₂	-					
			H ₂	0.9					
			CO ₂	13.8					
			290 BTU/SCF (DRY)						
			62,000 SCF/TON COAL						
KOPPERS- TOTZEK	OXYGEN BLOWN	BITUMINUS	H ₂	36.0	ATMOSPHERIC	LIQ. HYDRO- CARBONS = NIL PHENOLS = NIL AMMONIA = NIL SULFUR = 20 ASH = CONTAINS 4% OF INPUT CARBON AS THE UNBURNED PRODUCT	0.9 (O ₂)	0.35	68-70 (1),(3), (4)
	ATMOSPHERIC; 12,640 BTU/ ENTRAINED LB. (DRY)	CO	52.5						
		CH ₄	0.1						
	BED		C _n H _m	-					
			H ₂ S+CO ₂	0.4					
			N ₂	1.1					
			CO ₂	10.0					
			286 BTU/SCF (DRY)						
			67,000 SCF/TON COAL						
BGC/SLAGGING LURGI	OXYGEN BLOWN	SUB-BITUM.	H ₂	28.1	300-350 PSIG.	LIQ. HYDRO- CARBONS = 600 PHENOLS = PRESENT BUT NO VALUES GIVEN AMMONIA = PRESENT BUT NO VALUES GIVEN	0.5 (O ₂)	0.28	68 (1),(2), (3)
	PRESSURE, #8	13,000 BTU/ LB. (MOISTURE & ASH FREE)	CO	61.2					
	FIXED BED		CH ₄	7.7					
			C _n H _m	0.5					
			H ₂ S+CO ₂	-					
			N ₂	-					
			CO ₂	2.6					
			381 BTU/SCF						
			60,200 SCF/TON (MOISTURE & ASH-FREE BASIS)						
TEXACO	OXYGEN BLOWN	ILLINOIS	H ₂	39.0	350 PSIG (RANGE, 350- 2500 PSIG FOR UNITS NOW UNDER DESIGN)	LIQ. HYDRO- CARBONS = NIL PHENOLS = NIL AMMONIA = NIL SULFUR = ASH CONTAINS <2% CARBON	0.8-0.9	NIL (FEED ENTERS AS A 50% WATER SLURRY)	66-73 (1),(2), (3),(5), (6),(7)
	PRESSURE #6		CO	37.6					
	ENTRAINED	13,150 BTU/ LB. (DRY)	CH ₄	0.5					
	BED		C _n H _m	-					
			H ₂ S+CO ₂	1.5					
			N ₂	0.6					
			CO ₂	20.8					
			253 BTU/SCF						
			53,000 SCF/TON COAL						
COMBUSTION ENGINEERING	AIR BLOWN	PITTSBURGH/ KENTUCKY	H ₂	10.6/17.0	ATMOSPHERIC	LIQ. HYDRO- CARBONS = NIL PHENALS = NIL AMMONIA = NIL ASH = LOW IN CARBON; CHAR FROM PRODUCT GAS IS RETURNED TO GASIFIER	4.5 (AIR)	NO STEAM NEEDED	~ 60 (1),(2) (9),(10)
	ATMOSPHERIC		CO	24.7/22.1					
	ENTRAINED	BITUM. BTU/ LB. - NO DATA	CH ₄	0.0/0.0					
	BED		C _n H _m	-					
			H ₂ S+CO ₂	0.5/0.6					
			N ₂	60.2/53.3					
			CO ₂	4.0/7.0					
			112/127 BTU/SCF						
			SCF/TON 130,000/150,000						
SHELL-KOPPERS	OXYGEN BLOWN	BITUMINOUS, LOW ASH	H ₂	28.0	400-470 PSIG	LIQ. HYD. = NIL PHENOLS = NIL AMMONIA = TRACE ASH = LOW IN CARBON, <2% OF CARBON IS UNBURNED	0.7-0.9	NO DATA	74-77 (4),(8)
	PRESSURE		CO	62.2					
	ENTRAINED	11,800 BTU/ LB.	CH ₄	0.1					
	BED		C _n H _m	-					
			H ₂ S+CO ₂	0.9					
			N ₂	3.5					
			CO ₂	2.4					
			316 BTU/SCF						
			SCF/TON	70,600					

REPRODUCIBILITY OF
ORIGINAL PAGE IS PO

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

Figure IV-2. Candidate Gasification Systems

THE BDM CORPORATION

DATA SOURCES

1. "Low BTU Coal Gasification Processes," Hartman, Belk, Reagan, November 1978. ORNL/ENG/TM-13/V1, V2. Selected process descriptions are presented in this section for the 21 more promising processes selected for detailed investigation. The report summarizes work completed from July 1976 through August 1978.
2. EPRI AI-642, Project 239, January 1978. "Economic Studies of Coal Gasification Combined Cycle Systems for Electric Power Generation," Fluor Engineers and Constructors, Inc. EPRI Project Manager, Dr. Michael J. Gluckman.
3. SYNTHETIC FUELS DATA HANDBOOK, Dr. T. A. Hendrickson of Cameron Engineers, Inc., 1975.
4. Staeger, Hermann, "Entrained-Bed Coal Gasifiers Handle Double Throughput," CHEMICAL ENGINEERING, September 10, 1979, pg. 106-107.
5. Child, E. T., "Current Status of the Texaco Coal Gasification Process," paper presented at the AMMONIA FROM COAL SYMPOSIUM, TVA, Muscle Shoals, Alabama, May 8-10, 1979.
6. Schlenger, W. G., Texaco, Inc., "The Texaco Coal Gasification Process for Manufacture of Medium BTU Gas," presented at Joint Federal Energy and California Energy Commission CONFERENCE ON COAL USE FOR CALIFORNIA, Pasadena, California, May 9-11, 1978.
7. EPRI AF-880, Project 986-4, August 1978, "Preliminary Design Study for an Integrated Coal Gasification Combined Cycle Power Plant," Ralph M. Parsons, Co., Southern California Edison Company, Project Manager, T. L. Reed.
8. "The Sheel Koppers Coal Gasification Process Technical and Economic Prospects of its Integration with Combined Cycle Electricity Generation." ELEKTROTECHNEK 57 Pg. 414, June 1979.
9. CONSTRUCTION AND INITIAL OPERATION OF THE C-E COAL GASIFICATION PROCESS DEVELOPMENT UNIT, by R. C. Patterson of Combustion-Engineering, presented at ASME-IEEE-ASCE, Joint Power Generation Conference, September 1978, and Tenth Synthetic Pipeline Gas Symposium, October-November 1978.
10. "Coal Gasification," Quarterly Report, April-June 1978. U.S. Department of Energy, Division of Coal Conversion. DOE/ET-0067/2/ Publication Date - January 1979.
11. "Phase 1: The Pipeline Gas Demonstration Plant", Continental Oil Co.; E. F. Aul et. al.; FE2542-13, June 1979, U.S. Department of Energy.

Figure IV-2. Candidate Gasification Systems (Continued)

THE BDM CORPORATION

for the coal specified in Column 2 and generally at the specified pressure. This analysis can vary a considerable amount depending on the coal and the operating conditions. However, the analysis is informative in that it gives actual results obtained in the actual run. It should be emphasized that this analysis is for the raw gas, before any of the cleanup steps are performed.

4. Process Pressure

This gives the pressure at which the process was run for the analysis given. In a few instances, it gives a pressure range because of some uncertainty with the data. Also, in some cases the table shows, in parentheses, higher pressures at which the process is eventually expected to run.

5. By-Products

Gives the amounts of the various by-products such as liquid hydrocarbons (includes tars), phenols, ammonia, etc., in terms of pounds formed per ton of coal consumed. Values for sulfur are not given, even though this is a by-product. Sulfur is not included here since it is given as part of the gas analysis (under $H_2S + COS$) and because little other data was generally available. Also, no information is generally given regarding amounts of ash produced, although information is given, in some cases, on amounts of carbon in the ash or on the percent carbon in the coal that was unconverted.

This column is especially important because it gives a good indication as to the level of environmental problems one can expect from a given gasifier. The higher the levels of liquid hydrocarbons, phenols, etc., the greater the potential problems and expenses with worker exposure to these materials and with the waste water treatment system. Obviously, it also means a significant "disposal" problem when these substances are produced in any quantity. Generally, the sale of such materials is not easy or profitable unless the volume is large and they can be properly purified. A water treatment system can easily cost as much as 10 or 20 percent of the total plant cost when quantities of water and waste get to be significant.

THE BDM CORPORATION

6. Oxidant Demand

This tells the approximate demand of oxygen (O_2) or air, in terms of pounds per pound of coal consumed. The higher this value, the more must be spent on the capital and operating costs for an oxygen plant (or for air compressors).

7. Steam Demand

This gives the amount of steam that must be fed to the gasifier in terms of pounds per pound of coal fed.

8. Gasifier Efficiency

This gives the efficiency of the conversion of "heating value" of the coal into the "heating value" of the product gas. Because there are so many ways to calculate this value, and not all sources explain how it was calculated for their report, not too much dependence can be placed on this rather important parameter.

9. Data Sources

This gives the major sources of data for each process used in this table.

E. DATA QUALITY EVALUATION

1. Overview

Because the seven candidate processes must be examined in detail for technical and economic feasibility, as well as suitability for alternative applications, the quality of the published data sources used to characterize these processes was evaluated. Both technical and economic data were examined.

The technical data evaluation summarized in Figure IV-3 is based on the aggregate of data in the references listed in Section D of this chapter. The major conclusions to be drawn from that analysis are that the conceptual design studies and process descriptions examined provide only limited information with which to evaluate the quality and validity of the designs. Of particular interest is the almost complete lack of documentation on the design data base, and pilot plant configuration and operation.

FOLDOUT FRAME

	DRY LURGI	WINKLER	KOPPERS-TOTZEK	TEXACO	BGC-SLAGGING LURGI	COMBUSTION ENGINEERING	SHELL-KOPPERS
IS ADEQUATE DATA PROVIDED TO EVALUATE THE PLANT DESIGN?	NO	NO	NO	NO	NO	NO	NO
ARE DATA SOURCES REFERENCED?	YES	? (1)	? (1)	YES	YES	YES	YES
WAS A SIMILAR GASIFIER RUN ON THE DESIGN COAL?	YES	? (1)	? (1)	? (1)	? (1)	? (1)	? (1)
IS THE DESIGN COAL FULLY DESCRIBED?	YES	? (1)	? (1)	YES	NO (3)	? (1)	? (1)
IS THE DESIGN DATA ADEQUATE TO SCALE THE PLANT UP?	? (1)	NO (3)	NO (3)	? (1)	? (1)	NO (3)	NO (3)
ARE REASONABLY COMPLETE FLOW SHEETS PROVIDED?	YES (3)	NO (3)	NO (3)	YES (3)	YES (3)	NO (3)	NO (3)
IS ADEQUATE DESCRIPTIVE INFORMATION GIVEN ON MAJOR PLANT COMPONENTS SUCH AS CLEANUP PROCESSES, AND SULFUR UNITS?	NO	NO	NO	YES	NO	NO	NO
WERE FULL HEAT AND MATERIAL BALANCES DEVELOPED ON THE TEST PLANT?	? (1)	NO (3)	NO (3)	? (1)	? (1)	NO (3)	NO (3)
WAS THE PILOT/DEMONSTRATION PLANT COMPLETELY INTEGRATED, ie., QUENCH, ACID GAS REMOVAL, ETC.?	NO (3)	NO (3)	NO (2)	? (1)	NO (3)	NO (3)	NO (3)

Figure IV-3. Technical Data Quality Evaluation (4)

ARE REASONABLY COMPLETE FLOW SHEETS PROVIDED?	?	NO	NO	?	?	NO	NO
IS ADEQUATE DESCRIPTIVE INFORMATION GIVEN ON MAJOR PLANT COMPONENTS SUCH AS CLEANUP PROCESSES, AND SULFUR UNITS?	NO	NO	NO	YES	NO	NO	NO
WERE FULL HEAT AND MATERIAL BALANCES DEVELOPED ON THE TEST PLANT?	?	NO	NO	?	?	NO	NO
WAS THE PILOT/DEMONSTRATION PLANT COMPLETELY INTEGRATED, ie., QUENCH, ACID GAS REMOVAL, ETC.?	NO	NO	NO	?	NO	NO	NO
WAS THE PILOT/DEMONSTRATION PLANT OPERATED IN A CLOSED CYCLE MANNER, AS A FULL SCALE PLANT WOULD BE, INCLUDING RECYCLE, ETC.?	(2)	(3)	(2)	(2)	(2)	(2)	(2)

NOTES:

- (1) SOME INFORMATION PROVIDED, BUT INSUFFICIENT TO JUDGE ADEQUACY
- (2) NO INFORMATION GIVEN.
- (3) LIMITED INFORMATION GIVEN.

SEE FIGURE IV-2 FOR LIST OF DATA SOURCES FOR EACH SYSTEM.

THE BDM CORPORATION

As a result, the conclusions of the conceptual design studies cannot be critically evaluated from the published documents.

2. Economic Data

The economic evaluations studies were found to be invalid for either process comparisons or assessment of economic feasibility. In only two instances was methodology described and calculations presented. All other sources merely cite a cost of product in dollars per million BTU of product gas. In an era of inflation, rapidly rising oil prices and rapidly changing tax laws, historically adequate methods of process economic evaluation are today grossly inappropriate. As a prime example of the shortcomings in historical methods, and of how rapidly evaluations can become outdated, shortcomings in EPRI AI-642 are listed in Figure IV-4. This study, a comparison of five gasification designs for combined cycle generation, was one of only two studies to document its economic evaluation methodology and calculations, and uses traditional methods for costing conceptual designs. Of all the shortcomings listed, the failure to use escalators for both coal costs and gas market value have by far the biggest impact on both comparative process economics and evaluation of economic feasibility. Additionally, in almost every instance, the defects listed result in a heavy bias against capital intensive projects. Thus, the use of this methodology is likely to lead to the wrong decision on the economic feasibility of coal gasification, and to the choice of the wrong process on a comparative selection. These same defects are found in many other published studies, when the methodology is documented. The is that many published economic studies and gas cost estimates must be examined in detail before being used in process comparisons or economic evaluations. The appropriate methodology is the one specified by ESCOE, as described in detail in Section D of Chapter III.

I. TECHNICAL DATA

- o LIMITED FLOW SHEET DATA
- o DESIGN DATA UNDOCUMENTED
- o LIMITED DOCUMENTATION OF PILOT OPERATIONS AND CONFIGURATION

CONCLUSION: CONCEPTUAL DESIGN STUDIES CANNOT BE CRITICALLY EVALUATED FROM PUBLISHED DATA

II. ECONOMIC ANALYSES

- o ONLY TWO STUDIES PRESENT METHODOLOGY AND CALCULATIONS
- o EXAMPLES OF OUTDATED ASSUMPTIONS AND DEFECTS IN METHODOLOGY*
 - NO ESCALATORS - 1976 DOLLARS
 - NO INVESTMENT TAX CREDIT
 - DO NOT USE NORMAL RED ACCOUNTING FOR DEPRECIATION (ACCELERATED DEPRECIATION PLUS RESERVE FOR DEFERRED TAXES)
 - NO STATE TAX
 - 10% COST OF CAPITAL (12% TODAY)
 - 50/50 DEBT/EQUITY RATIO (75/25 TODAY)
 - 52% FEDERAL CORPORATE TAX (46% TODAY)
 - CONSTRUCTION LOAN VALUED AT REGULATED RATE OF RETURN RATHER THAN COST OF CAPITAL

- CONCLUSIONS:
- (1) MOST PUBLISHED ECONOMIC EVALUATIONS ARE NOT VALID FOR EITHER PROCESS COMPARISONS OR FEASIBILITY ANALYSIS
 - (2) DEFECTS IN METHODOLOGY CREATE HEAVY BIAS AGAINST CAPITAL INTENSIVE PROJECTS

* EPRI AI-642, JAN. 1978

Figure IV-4. Summary of Evaluation of Quality of Published Data for Seven Candidate Processes

THE BDM CORPORATION

CHAPTER V POTENTIAL INDUSTRIAL MARKETS

A. BACKGROUND AND PURPOSE

The economic credibility of a coal conversion complex can be realistically assessed only after detailed data on all factors which will affect the cost and use of the various products of such a facility have been quantified and realistically projected into the future. Such an analysis must include characteristics of the industries which will potentially utilize these products. The major end-uses of coal conversion products, and the costs of such products to the industrial user, as will the cost of alternatives to these products, must be as realistically assessed as possible. For a coal conversion product to be commercially viable, it obviously must be attractive from the standpoint of cost. However, in the present environment it is likely that the cost to the end-user of such products will be strongly affected, for example, by possible government subsidies which would lower cost and by governmental pollution control standards, which if more strict in the future could raise the cost of synthetic fuels. Regardless of factors such as these, it is essential that the potential industrial users of coal conversion products be clearly identified.

The purpose of this section is to describe the characteristics of the potential industrial users of coal conversion products. This description is made at these levels of detail - national industrial users, regional users, and specific industries in the Northern Alabama area. At the national level, major industrial users of energy are identified and future costs of both synthetic coal-derived fuels and alternative fossil fuel sources are estimated. At the regional level, the potential industrial demand for medium-BTU gas (MBG) derived from coal, is given. At the Northern Alabama market level, specific plants are listed and categorized according to the potential attractiveness of MBG to these plants.

THE BDM CORPORATION

B. SUMMARY OF FINDINGS

1. National and Southeast Regional Markets

The principal findings of the analysis of the potential national market demand for the products of a coal gasification process are summarized below:

- (a) Energy consumption by industry can be used as a first-order selection criteria for assessing potential demand for synthetic fuels.
- (b) Three industries - metals, chemicals and paper making -utilize over one-half of all purchased industrial electrical energy in this country.
- (c) Natural gas provides the majority of the fossil fuel consumed on the national level by energy-intensive industries.
- (d) By-products of the coal gasification process, such as sulfur, carbon dioxide and slag/ash, have existing commercial uses to some extent and the use of these by-products in the future will probably increase.
- (e) Projected costs of the medium-BTU gas produced by a large scale gasification facility is generally higher than the linearly projected costs of competing fuels. However, it is unlikely that these linear projections of fuel costs are valid.

The results of a survey of studies which analyze regional demand for the medium-BTU gas produced by coal gasification are as follows:

- (a) Within the metropolitan markets in the surveyed region, the most important potential markets for MBG are petroleum refining, steel production, and chemical manufacturing.
- (b) In the future two primary competing fuels for MBG will probably be residual fuel oil and direct fluidized bed combustion of coal.
- (c) The credibility of the projected regional demand for MBG is difficult to ascertain because of uncertainty in the future prices of alternative fuels, future governmental policy, and the difficulty in quantifying the value of an uninterruptible supply of fuel.

THE BDM CORPORATION

2. Northern Alabama Markets

The following conclusions can be deduced from the market survey of the Northern Alabama region:

- (a) Several large energy-intensive industries which might be attracted to utilization of commercially competitive, non-interruptible medium-BTU gas are already present in this region.
- (b) The potentiality exists of both expanding the size and number of existing industries in this region if a large source of MBG became available, or else attracting entirely new types of energy-intensive industries, such as can manufacturers.

C. NATIONAL AND SOUTHEAST REGIONAL MARKETS

1. Overview

The purpose of this section of the report is to examine the characteristics of the potential market for products generated by coal gasification and to provide a first order estimate of the cost of the medium-BTU gas which is the primary product of such a process. The projected cost of the MBG is then compared with projections of the cost of competing sources of energy.

Two primary markets are analyzed - the national market and the southeastern regional market. At the national level, major industrial users of energy are identified and categorized. The major national end-uses of fossil fuel energy are identified and the principal industrial groups which are heavy energy users are listed. Additionally, the principal national uses of coal gasification products other than MBG are determined.

To obtain an estimate of regional market demand, the potential demand for medium-BTU gas for five metropolitan areas are provided. A first order estimate of the price of the MBG which might be provided to markets such as these is developed. These price estimates are examined parametrically as a function of capital investment and operating cost. Finally, the present costs of competing fuels, and their projected costs

THE BDM CORPORATION

out to 1995, are compared with sample cost estimates of the MBG gas produced by selected coal gasification processes.

Coal utilization complexes currently envisioned would produce medium-BTU gas (MBG) for commercial market beginning mid 1980's through the lifetime of the plant, expected to be 20 years. Other products produced by the facility are sulphur, steam, carbon dioxide, ash and slag. Figure V-1 depicts a simplified 20,000 TPD gasifier and gas clean up. It is assumed the plant will be located in Northern Alabama and will be utility operated, that is oriented toward production of MBG for the region.

An overview of gasifier products and applications is shown on Figure V-2. The table illustrates generic gas end uses, primarily as a use for boilers, furnaces and kilns, and also as a chemical feedstock such as ammonia, methanol, etc. Pipeline gas (High BTU) is not examined in this analysis; preliminary economics analysis indicates a large market for MBG. Low-BTU gas is unattractive for chemical feedstocks and certain heating applications due to high nitrogen content.

2. National Industry Energy Uses

Industries depicted on Figure V-3 account for about 67 percent of the total purchased fuels in the United States. This figure also shows Standard Industrial Codes (SIC). Therefore, energy consumption can be used as a selection criteria for synthetic fuels industrial application.

For the food processing industry group (SIC 20) the major application of coal utilization appears to be boiler fuel. Over sixty percent of the total energy consumption in the food industry in 1974 was for boiler fuel. Figure V-4, V-5, and V-6 show national end uses of fossil energy; national industrial energy consumption by fuel type and end use; and national end uses of purchased fuel and electricity.

Manufacturing industrial usage of purchased electricity is shown on Figure V-7. The metals, chemicals, and paper industries use over half of all purchased electricity. The majority of this energy may be used for machinery drives, but such industries as aluminum use large amounts in processing metals.

THE BDM CORPORATION

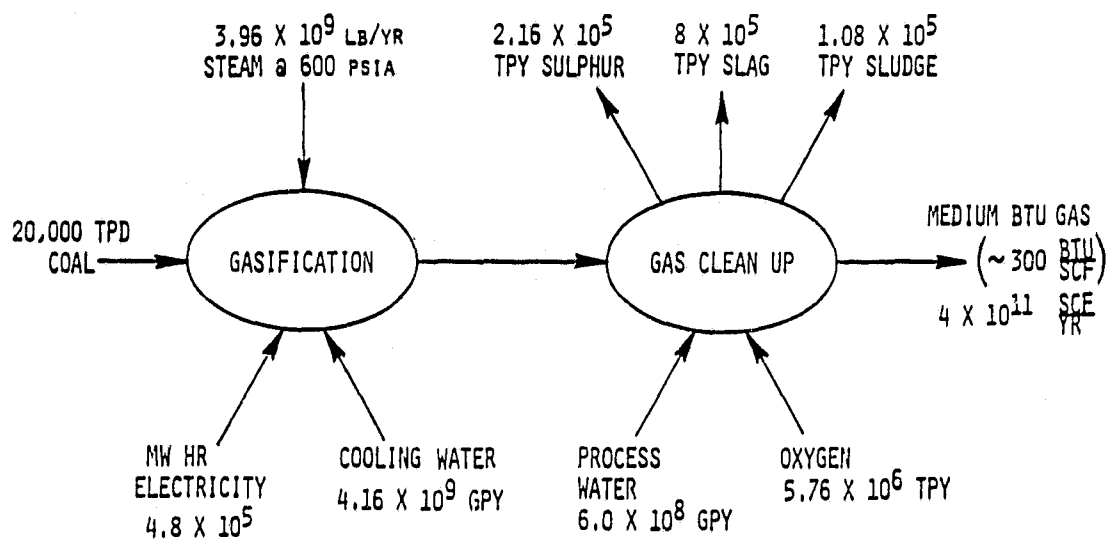


Figure V-1. Simplified Gasification Process

END USES	COMPOSITION			COMMENTS
	DESIRABLE	NOT DESIRABLE BUT ACCEPTABLE	UNACCEPTABLE	
FUEL GAS	H_2, CO, CH_4, C_2-C_5S	$N_2, CO_2^{(1)}$	$H_2S, ORGANIC SULFURS^{(1)}, PARTICULATES$	LOW AND MEDIUM BTU GAS - FOR USE AS A FUEL IN BOILERS, HEATING PROCESSES AND COMBUSTION TURBINES; IN THE LATTER, THE PRESENCE OF INERT GASES SUCH AS CO_2 AND N_2 ARE GENERALLY CONSIDERED DESIRABLE.
CHEMICAL FEED STOCK (SYNTHESIS GAS)	$H_2, CO^{(3)}$	$CH_4, C_2-C_5S, N_2, CO_2^{(4)}$	$H_2S, ORGANIC SULFURS, PARTICULATES$	MEDIUM BTU GAS - FOR USE IN THE PRODUCTION OF CHEMICALS SUCH AS AMMONIA, METHANAL AND OXO ALCOHOLS/ALDEHYDES. IN THE PRODUCTION OF AMMONIA, THE PRESENCE OF NITROGEN DOES NOT PRESENT A PROBLEM SINCE IT IS ONE OF THE REACTANTS. ALSO, THIS GAS CAN BE USED TO PRODUCE METHANE, (SNG), WHERE METHANE AND THE C_2-C_5 HYDROCARBONS IN THE GAS ARE DESIRABLE. IN GENERAL, HOWEVER, THE MAIN REACTANTS ARE H_2 AND CO AND THE OTHER COMPONENTS SUCH AS CO_2, N_2, CH_4 , ETC., SIMPLY DILUTE THE GAS AND DECREASE THE OVERALL CONVERSION RATES.
SNG (SYNTHETIC NATURAL GAS)	CH_4, C_2-C_5	H_2, CO, N_2, CO_2	$H_2S, ORGANIC SULFURS, PARTICULATES$	HIGH BTU GAS - FOR USE AS PIPELINE GAS WHICH IS USED FOR FUEL AND AS A CHEMICAL INTERMEDIATE FOR PRODUCTION OF SYNTHESIS GAS AND CERTAIN OTHER CHEMICALS. GENERALLY THE H_2 AND CO ARE NOT DESIRABLE BECAUSE OF THEIR INHERITANTLY LOW HEATING VALUES. THIS IS THE ONLY ONE OF THE GASIFICATION PRODUCTS THAT CAN BE ECONOMICALLY TRANSPORTED MORE THAN ONE OR TWO HUNDRED MILES.

(1) ORGANIC SULFURS INCLUDE COS, MERCAPTANS, AND THIOPHENES.

Figure V-2. Gasifier Product Applications Matrix Composition of Gases as a Function of End Uses

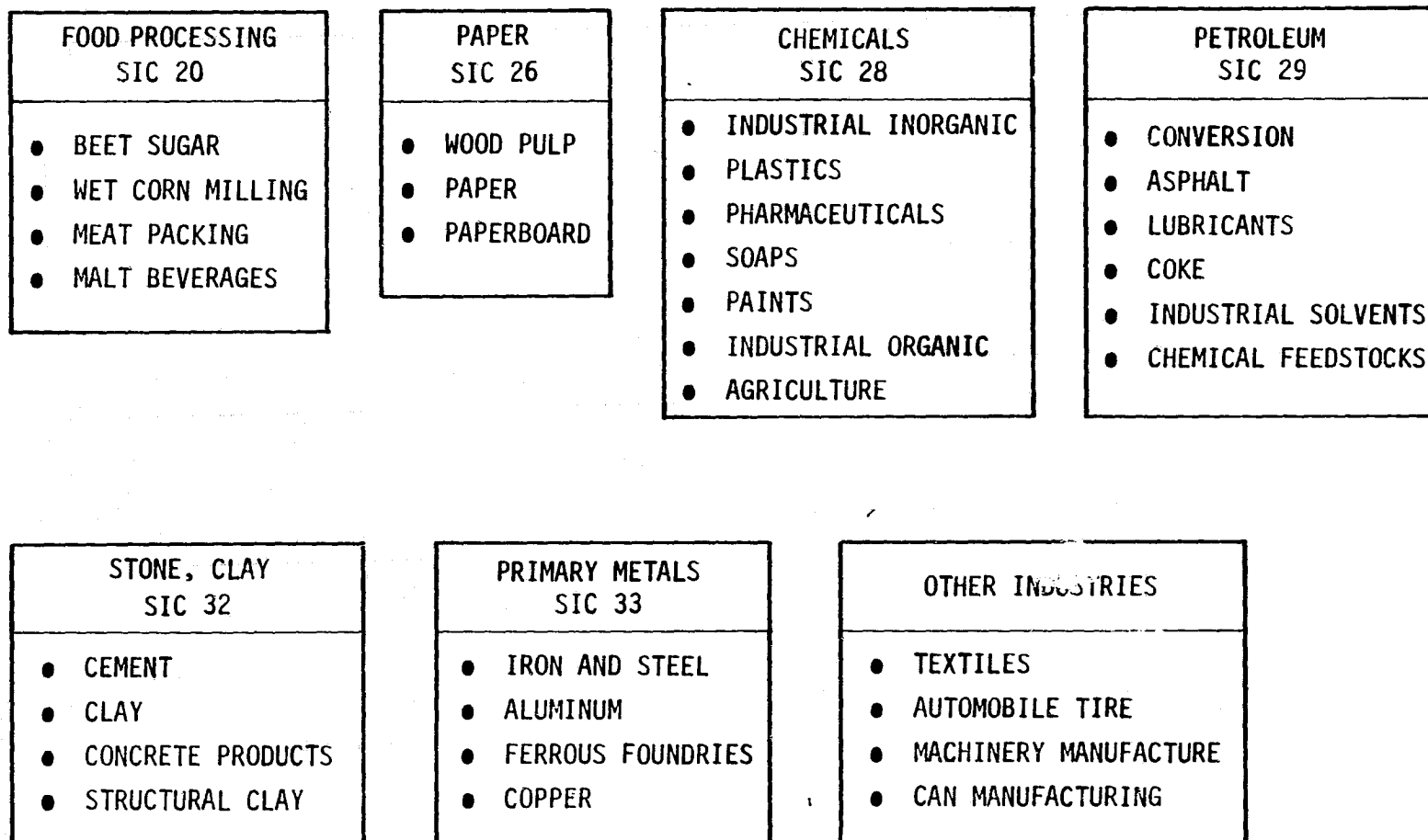


Figure V-3. Industries Which Have High Potential for Synthetic Fuels

THE BDM CORPORATION

Industry	Percent of Total Energy Usage		
	Steam & Power Generation	Process Heat	Machinery Drives
Food Processing	62.8	11.7	-
Pulp & Paper	74.9	12.6	-
Chemicals	62.0	21.8	4.7
Refining	21.8	74.8	1.5
Stone, Clay, Glass	0.5	83.2	1.7
Primary Metals	16.6	43.7	-

Notes:

Fossil energy includes coal, coke, distillate, and residual oil, LPG, and natural gas. It does not include refinery off-gases, blast furnace gas, or coke-over gas. Coal used in coke production in SIC 33 is not included.

Figure V-4. National End Uses of Purchased Fossil Fuel Energy

10¹² BTU Per Year

<u>Fuel</u>	<u>Boilers</u>	<u>Process Heaters</u>	<u>Kilns & Furnaces</u>	<u>Machine Drives</u>	<u>Other Use</u>	<u>Total for Identified Industries</u>	<u>Total, All Industries</u>
Natural Gas	2006.2	1417.0	1271.1	118.4	815.8	5628.5	6620.0
Oil ⁽¹⁾	763.0	884.3	339.8	25.5	189.2	2201.8	2534.1
Coal & Coke	<u>752.3</u>	<u>-</u>	<u>237.6</u>	<u>-</u>	<u>147.4</u>	<u>1137.3</u>	<u>1423.1</u>
Total	3521.5	2301.3	1848.5	143.9	1152.4	8967.6	10557.2
Total, All Fuels, All Industries							12509.8

Notes:

(1) Includes distillate, residual, miscellaneous petroleum products, and LPG.

Figure V-5. 1974 National Industrial Energy Consumption by Fuel Type and End Use

10¹² BTU/Year

<u>Fuel (1)</u>	<u>End Use: (2)</u>	<u>Space Conditioning and Lighting</u>	<u>Direct Heat</u>	<u>Steam Production</u>	<u>Electric Power Generation</u>	<u>Machinery Drives</u>	<u>Other</u>	<u>Total</u>
Coal		4.6	237.6	544.8	228.0	-	263.9	1278.9
Coke			29.4	1.7			113.1	144.2
Distillate Oil		6.2	144.6	141.3	12.7	28.9	214.5	548.2
Residual Oil		7.4	578.6	555.5	99.8	15.7	238.6	1495.6
Misc. Petroleum Products			382.2		0.8	1.1		384.1
LPG			30.9	9.8	0.7	0.6	64.2	106.2
Natural Gas		39.8	2705.9	1699.5	376.9	118.4	1679.5	6620.0
Electric Power		78.2	102.7		(292.5)	809.8	1013.0	1711.2
Other			61.3	1004.0	45.1		822.2	1932.6
Total		136.2	4273.2	3956.6	471.5	974.5	4409.0	14221.0

Notes:

(1) Fuels not considered: Refinery fuel gas, blast furnace gas, coke-over gas, hydroelectric power.

(2) End-uses not considered: Raw materials, coke production, electrolysis.

Sources: Energy Consumption Data Base, DOE/EIA - 0014, June 1978.Figure V-6. Identification of Purchased Fuels and Electricity, 1974,
National Manufacturing Industries

RANK	INDUSTRY TYPE	PERCENT OF TOTAL ENERGY UTILIZED
1	METALS	29
2	CHEMICALS	23
3	PAPER	10
4	FOOD	5
5	TRANSPORTATION EQUIPMENT	5
6	PETROLEUM AND COAL	5
7	STONE, CLAY AND GLASS	4
8	TEXTILES	4
9	ELECTRICAL MACHINERY	4
10	NON-ELECTRICAL MACHINERY	3
ALL OTHERS		8

Figure V-7. Manufacturing Industries Electrical Energy Consumption (1976)

THE BDM CORPORATION

3. Southeast Region and Alabama Fossil Fuel Usage

Regions throughout the United States vary in industrial emphasis, labor, availability of energy sources, raw materials, water, and transportation. In general the southeast region enjoys the supply of all the necessary industrial resources. Figure V-8 illustrates the six major energy intensive industries purchased fuels (other than electricity) in 1976. Paper, chemicals, stone/clay, and primary metals consumed the bulk of fossil fuel energy. Petroleum industry in Alabama was non-existent. The 20,000 TPD gasifier could supply almost half of the 1976 state of Alabama fossil fuel requirement. Obviously, current state suppliers of fossil fuel energy could not be replaced. Most of the users of the state gasifier would have to be new customers or industries attracted to the state by the synthetic fuel complex. Primary industries which could be expanded are new plants attracted to the state are:

- Food
- Paper
- Chemicals
- Stone, Clay
- Primary Metals

4. Eastern Metropolitan Market Usage

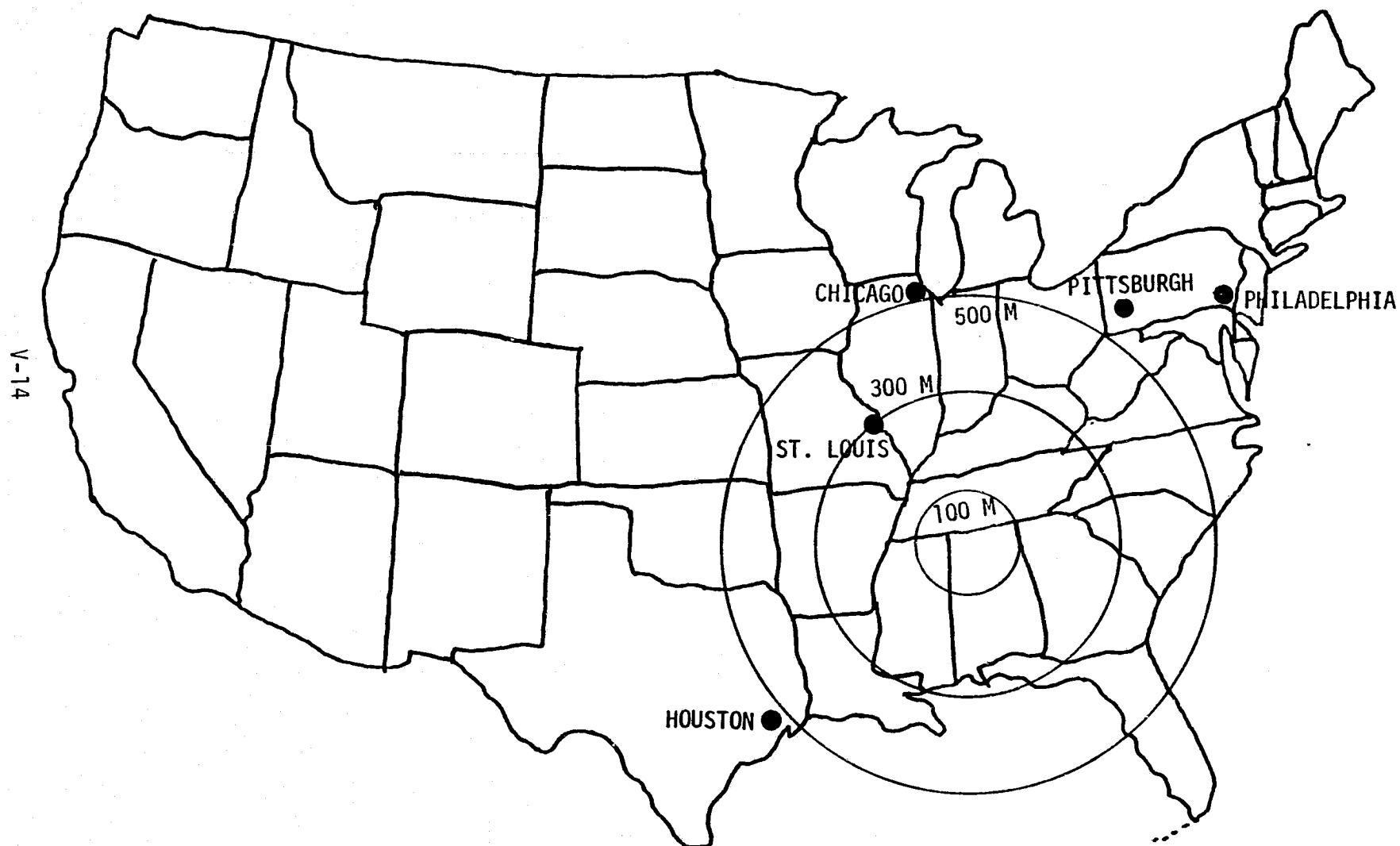
Five metropolitan markets shown on Figure V-9 were surveyed by Stanford Research Institute^{*} to characterize the principal industrial markets from coal utilization. Market penetration to year 2000 was examined by defining potential user requirements. Figure V9 illustrates the five market areas. Previous studies estimated MBG was not economically transportable over 200 miles. As can be seen on the map the nearest metropolitan area is St. Louis, at 300 miles distance. In order to establish general market trends, and in the event MBG is transportable similar to pipe-line gas, results from the SRI study are included. The study concluded that within the five metropolitan areas, the most important market potential for MBG are petroleum refining, steel production, and chemical

^{*} Market opportunities for Low and Intermediate BTU Gas from Coal in Selected areas of Industrial Concentration, June 1978.

State	Food SIC 20	Paper SIC 26	Chemicals SIC 28	Petroleum SIC 29	Stone, Clay SIC 32	Primary Metals SIC 33	Others	Total
Alabama	6.2	72.3	47.8	0	28.5	65.0	35.6	255.4
Tennessee	16.2	27.4	108.9	1.5	26.0	16.2	34.4	230.6
Georgia	13.6	70.8	22.9	2.4	29.4	6.5	56.0	201.6
Kentucky	12.8	7.6	31.0	0	11.1	55.2	35.0	152.7

Source: Annual Survey of Manufactures 1976: Fuels and Electric Energy Consumed, Report No. M76(AS)-4.2, U.S. Department of Commerce, Bureau of Census, May 76.

Figure V-8. Purchased Fuels Other Than Electricity by State and Industry (10^{12} BTU/YR, 1976)



V-14

Figure V-9. Comparison of the Five Metropolitan Markets Surveyed with Distance from North Alabama

THE BDM CORPORATION

manufacturing. These industries are characterized by large sustained energy requirements. For petroleum and steel industry it is estimated that thirty percent of the energy requirements can be supplied by MBG. For chemical manufacturing all of the purchased fuel requirements can be supplied by MBG. National projections for the three industries are shown below:

	TRILLIONS OF BTU PER YEAR	
	<u>1985</u>	<u>2000</u>
DEMAND FOR TOTAL ENERGY, PETROLEUM REFINING	3,600	4,500
DEMAND FOR PURCHASED ENERGY CHEMICALS	3,800	5,100
DEMAND FOR PURCHASED ENERGY BASIC STEEL	<u>1,500</u>	<u>1,700</u>
TOTAL FOR 3 KEY INDUSTRIES	8,900	11,300
MBG MARKET PENETRATION PROJECTIONS	650	1,470

Fuel projections for the five metropolitan areas are defined below:

	TRILLIONS OF BTU PER YEAR	
	<u>1985</u>	<u>2000</u>
HOUSTON	149	334
CHICAGO	69	119
PITTSBURGH	25	42
ST. LOUIS	20	39
PHILADELPHIA	37	61

Two primary competing fuels for MBG are residual fuel oil and direct combustion. Actual market value will be a function of price, supply, environmental constraints, and fuel handling costs. Further, chemical feedstock uses of MBG may achieve economic viability before fuels application.

THE BDM CORPORATION

The SRI study characterized industries in the five surveyed metropolitan areas by energy usage, demand schedules, and MBG retrofit or new installation suitability. Figure V-10 summarizes the industry grouping and industrial applications. It is interesting to note chemicals, paper, and primary metals rate high, as compared to the southeast region (Figure V-8), whereas petroleum and food industries are small in Alabama. The stone and clay industry is not rated high for industrial fuel application for MBG.

5. National Uses of Coal Utilization Products Other Than Medium-BTU Gas

Coal gasification products other than medium-BTU gas were briefly analyzed from a national market sense. Figure V-11 through V-14 illustrate uses for:

- Sulphur
- Sulfuric acid
- Carbon dioxide
- Fly ash, Bottom ash and Slag

Most sulphur goes into making sulphuric acid which is used to produce fertilizer. A growing market for carbon dioxide is in food refrigeration and carbonation. The majority of ash is dumped with approximately 20% being utilized. Of the ash portion being utilized, most is for unidentified purposes.

6. Cost and Economic Analysis

Successful commercialization of a synthetic fuel complex depends on the product costs. Accurate development, construction, and operating cost are necessary to obtain reasonable price estimates. Detailed systems parameters, financial data schedules of development and operation are also required to do cash flow projections. Since the coal utilization facility has not yet been conceptually designed, a cost parametric analysis is useful. Competing fuel prices such as natural gas, boiler fuel, electricity, and liquid natural gas must be projected since fuel prices, in general, are assumed to retain a fixed ratio to each other.

The capital investment method for a large synthetic fuels complex has not been determined. Government funding, utility, and commercial

Industry	Technically Suitable Applications		Energy Demand Continuity	Energy Demand Seasonality			Remarks
	Retrofit	New		Less Than 10%	10%-30%	More Than 30%	
Group I							
Petroleum refining	X	X	Continuous	X			Large, continuous operations
Chemicals	X	X	Continuous	X			Large, continuous operations, sometimes smaller than refining
Basic steel	X	X	Continuously cycling	X			Large, continuous operations
Group II							
Rubber*	X	X	Usually continuous	X			Primarily process steam requirement
Pulp	X	X	Continuous	X			Ditto. Remote locations, use by-product fuels
Paper*	X	X	Continuous	X	X		Ditto. Metropolitan locations
Food processing	X	X	Nearly continuous				Ditto. Clean-up operations sustain energy demand continuity
Group III							
Fabricated metals, ex. can mfg.	X	X	Up to 50% reduction weekends			X	Primarily space heat component
Electrical eqpt. and machinery	X	X	Up to 50% reduction weekends			X	Primarily space heat component
Machinery, ex. electrical	X	X	Up to 50% reduction weekends			X	Primarily space heat component
Transportation equipment	X	X	Up to 50% reduction weekends			X	Primarily space heat component
Can manufacturing		X	50% reduction weekends		X		Retrofit unlikely for direct-heat uses. Natural gas strongly preferred, propane/air standby
Group IV							
Nonferrous primary metals		X	Continuous	X			Remotely located potentials. Demands process- and product-specific
Stone and clay*	X	X	Variable	X			
Iron ore beneficiation*	X	X	Continuous	X			
Glass		X	Continuous	X			

*Direct-firing of coal may be preferred option.

Figure V-10. Summary of Industrial Fuel Applications for Medium-BTU Gas

THE BDM CORPORATION

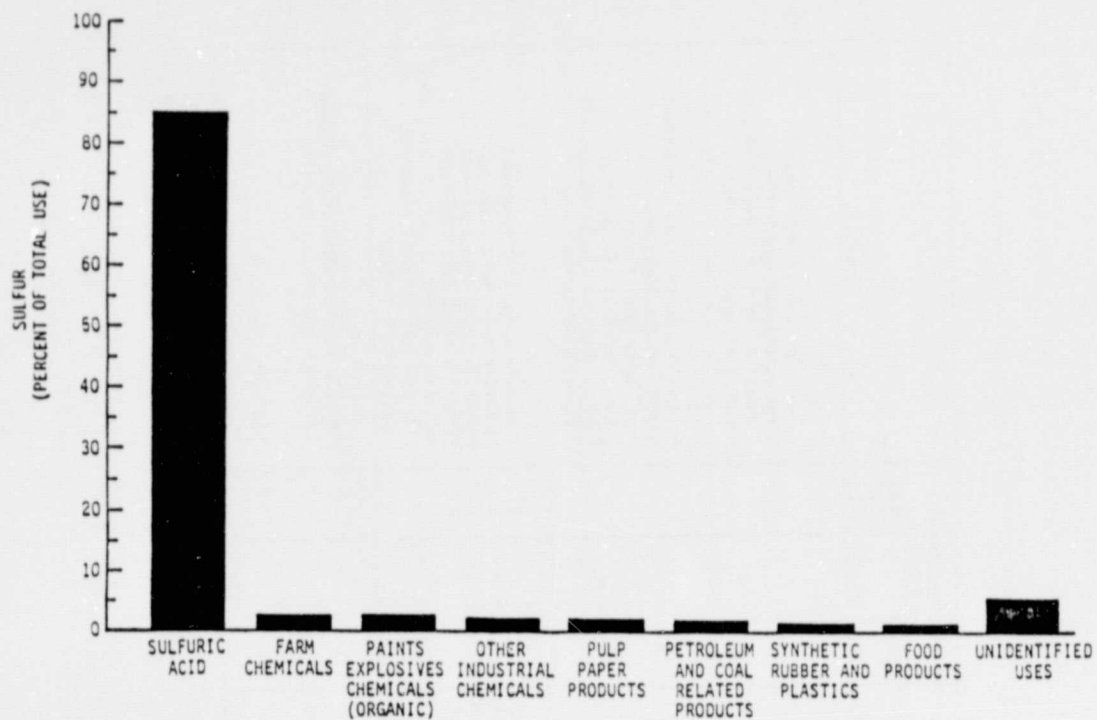


Figure V-11. National End Uses of Elemental Sulfur

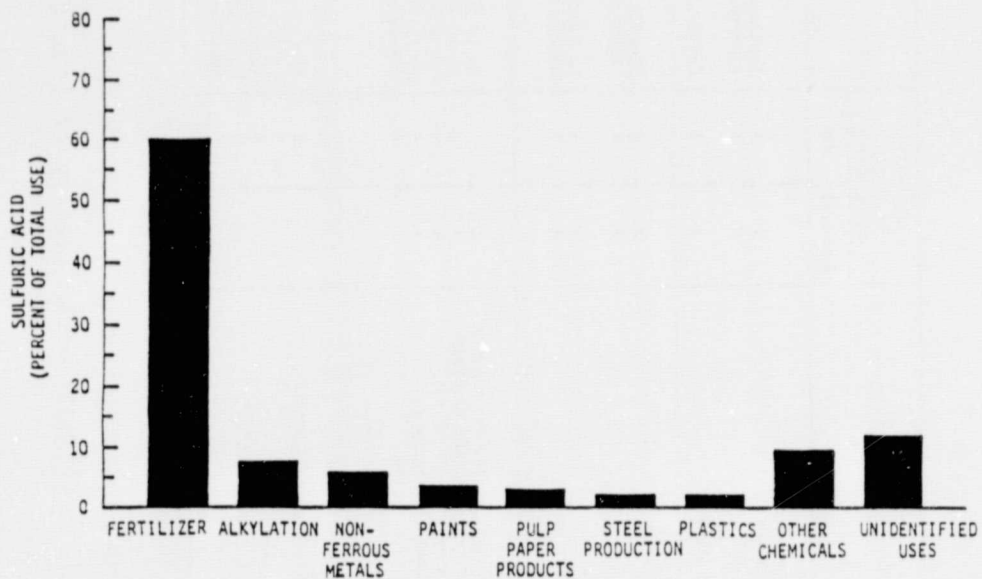


Figure V-12. National End Uses of Sulfuric Acid

THE BDM CORPORATION

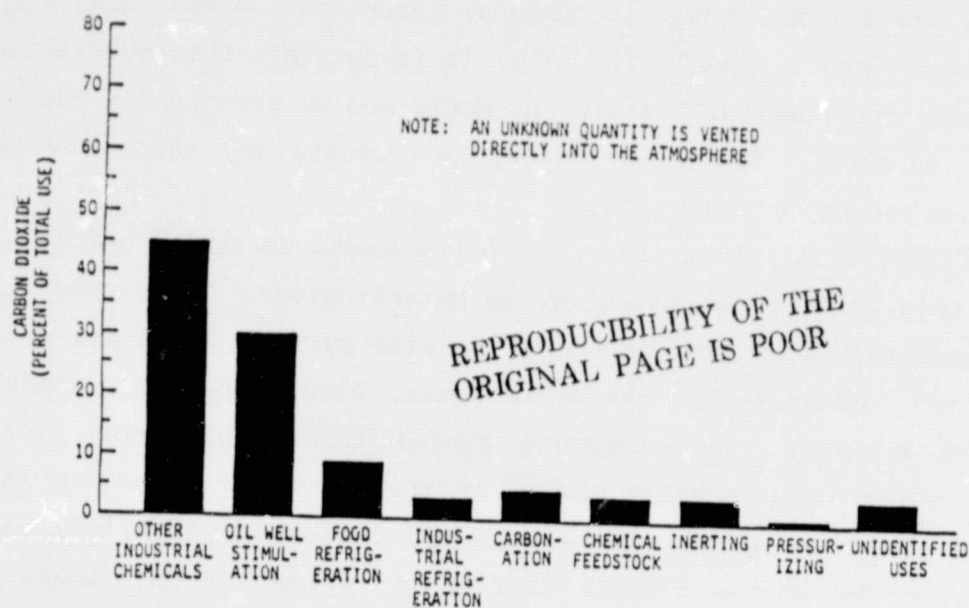


Figure V-13. National End Uses of Carbon Dioxide

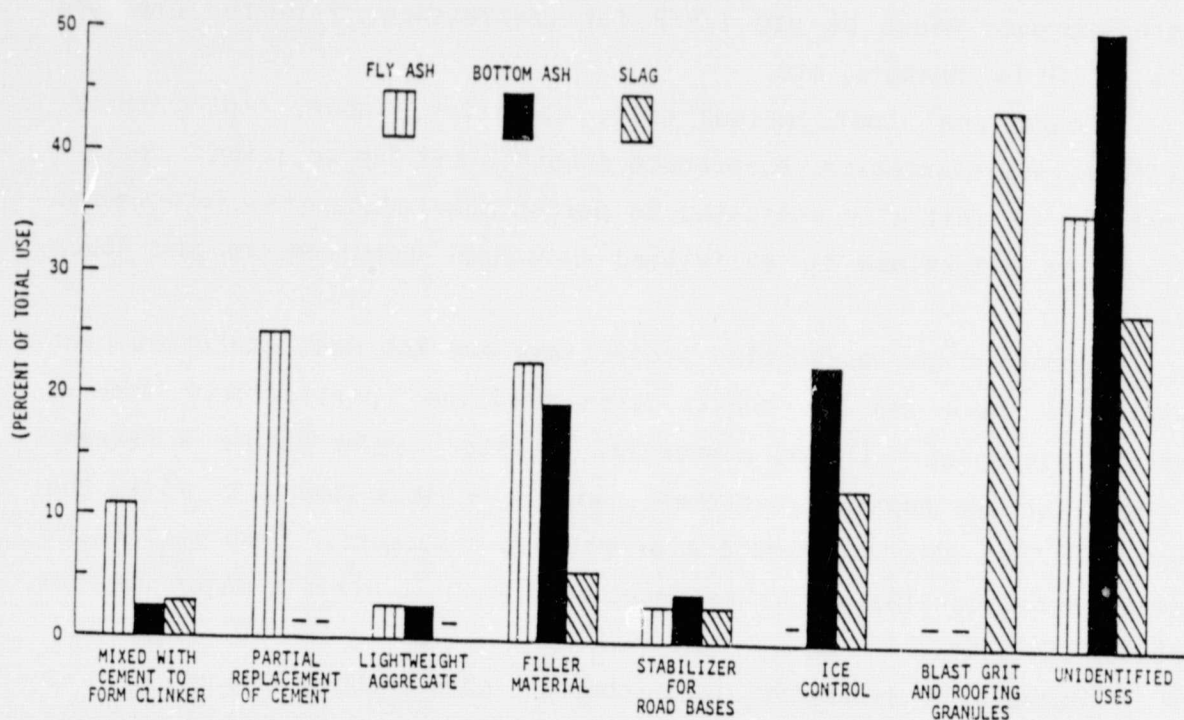


Figure V-14. National End Uses of Fly Ash, Bottom Ash and Slag
(80% of Total Capacity is Dumped)

THE BDM CORPORATION

investments are all possible. The capital investment method impacts operating cost and financial analysis. Also it is possible the federal government may subsidize coal utilization products and/or provide tax incentives and energy mandates. State and county governments may also provide tax support, bond issues, or land grants.

Figure V-15 illustrates cost and economic variables which make up a product cost, price, and market value determination. The synthetic fuel complex characteristics are necessary to size product streams and types, site location, schedule of investment costs, plant lifetime, schedule of plant being on line, and competing synthetic fuel complexes. Capital investment costs include construction of the complex, supporting facilities, and site preparation. Since a 20,000 ton per day facility has not been built in the United States, confidence in capital investment costs will not be obtained until firm designs are complete. The architect/engineer doing the actual construction will probably have the most accurate capital investment costs. Established vendors can provide unit costs whose values strongly depend on size and materials of construction. An initial estimate approach might be use \$/BHP for compressors, \$/lb for pressure vessels, \$/BTU for heaters, etc.

Operational cost include coal, utilities, labor, debt service, maintenance, administration, by-product credits, and depreciation. Operating cost can be initially estimated as percentages of capital investment. Labor can be determined by estimating personnel requirements and labor scales.

Economic and accounting projections are the most important part of synthetic fuel complex construction decision, particularly from a commercial viewpoint. If the commercial investor cannot obtain a reasonable profit on the capital investment, with a minimum amount of risk, the project will not attract investors or product customers. Complete understanding of tax considerations is necessary since it plays a major role in investment decisions.

Because a synthetic fuel complex can produce products at a reasonable price does not mean it will be a commercial success. Commercial

THE BDM CORPORATION

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

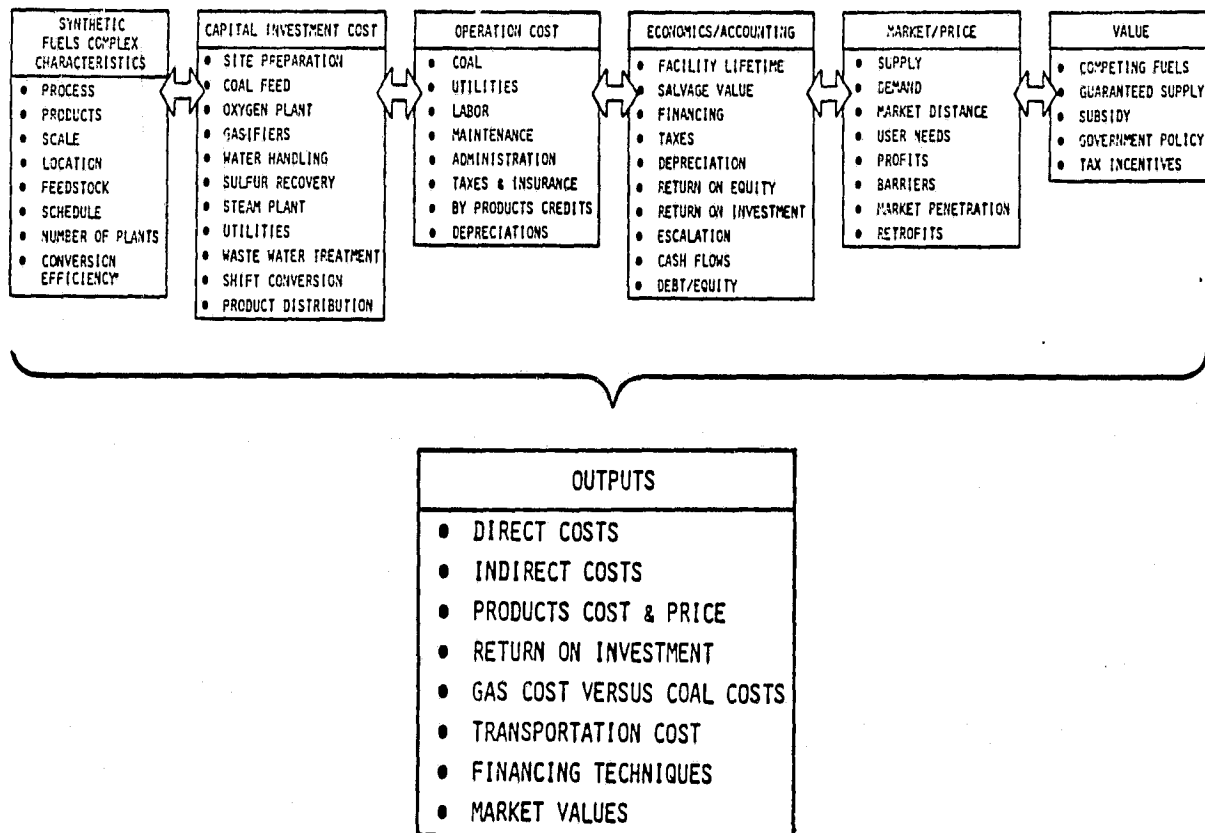


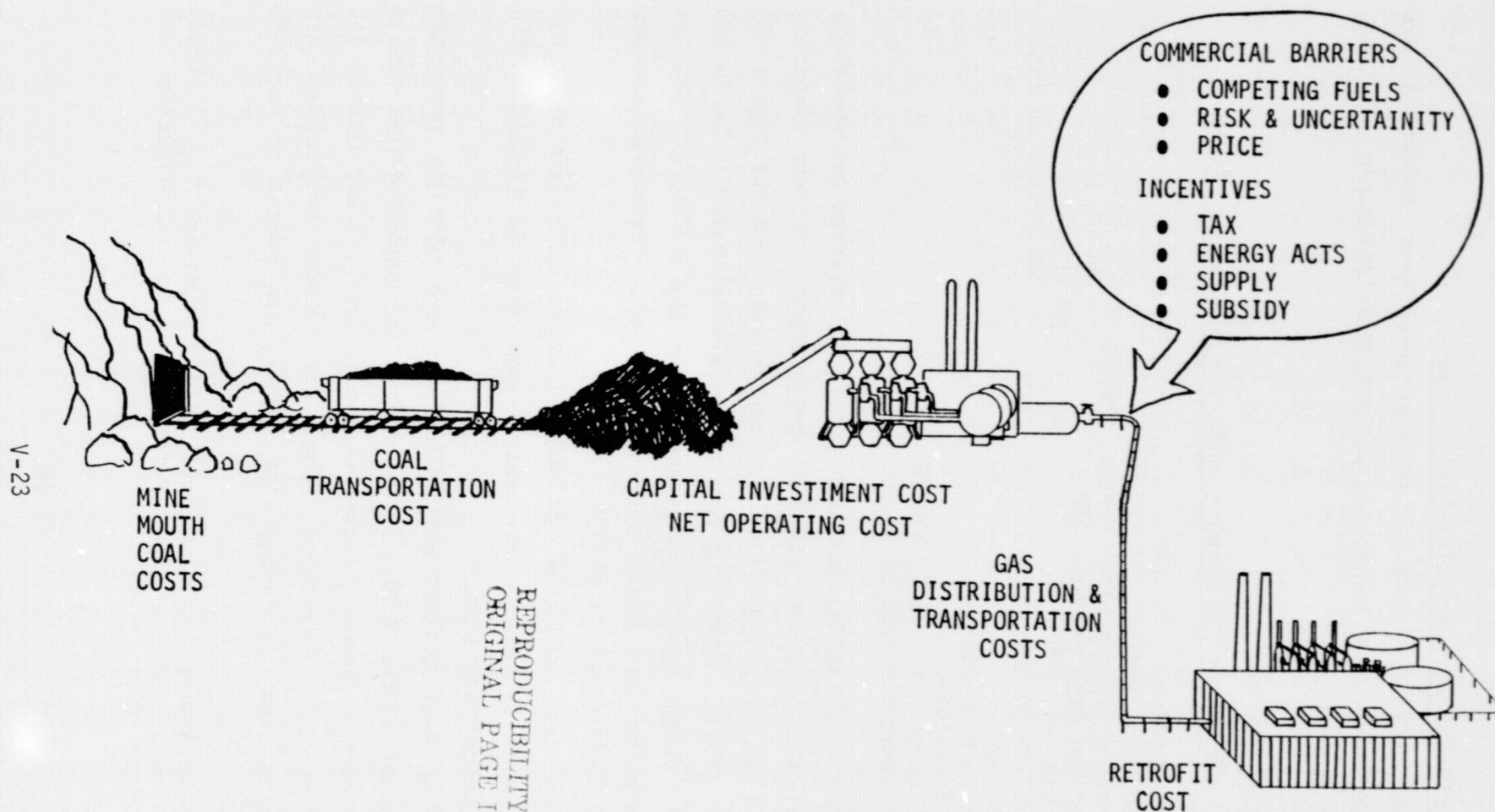
Figure V-15. Coal-Based Synthetic Fuels Cost/Price/Economics Variables

THE BDM CORPORATION

barriers such as market distance, plant retrofit cost, uncertainty, and actual demand for the products will lessen or add to the market price. Currently there is no market for medium-BTU gas, current plants must be attracted by supply and price, and new industries must build to utilize the products. As was shown earlier, a 20,000 TPD gasification facility will produce half of the purchased Alabama industry fossil fuels requirements. Current suppliers of fossil fuels cannot be driven from the market by government subsidies. Therefore most of the gasification products will probably have to be new plants being constructed within approximately 200 miles of the site.

The actual value of the synthetic fuels will be difficult to quantify because of competing fuel prices, guaranteed supply, possible government subsidy, and government policy. The primary competing fuels are natural gas, boiler fuel and electricity. Obviously the government is trying to reduce imported oils; however, agreements on large imports of Mexican natural gas were recently signed. Therefore, projection of government actions and international policy is difficult to predict.

Outputs from a cost and economic analysis will primarily be products cost escalated over the life of the facility. All direct and indirect costs will have to be projected. Cost trade-offs such as coal, transportation, net operating costs, can be determined. Total cost analysis from a systems approach is shown in Figure V-16. Costs have to be determined from the mine-mouth through user plant retrofit cost. Commercial and environmental restriction barriers will have to be overcome at each step of materials flow. Mine-mouth low sulphur coal is estimated to be \$40-\$60 per ton in the mid 1980's, with transportation cost \$5-\$20 per ton (depending on distance). Gasification and transportation cost in mid 1980's (including investment and operating) to the industrial user are estimated to be \$7.25-\$8.99/MMBTU.



REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

Figure V-16. Coal Utilization Cost Analysis

THE BDM CORPORATION

7. Medium-BTU Gas and Competing Fuel Prices

Since synthetic fuel complex detailed investment, operating, and financial data are not available, a cost estimating relationship (CER) was used.* The CER is as follows:

$$\text{Product Cost} = \frac{tT + N + .05 (C-W) + .005 P + \frac{48}{52} (1-d) r (C+W)}{G}$$

t = Coal Price, \$/Ton

T = Coal Feed, MM TONSMR

N = Net Operating Expense after Credit, \$MM/YR

C = Total Capital Requirements, \$MM

W = Working Capital, \$MM

P = Annual Return on Rate Base

d = Debt Fraction

r = Annual Return on Equity

I = Capital Investment

G = Annual Product Rate, X1012 BTU/YR

It was assumed C = 1.25786 I .

Parameterizing capital investment cost and average net operating cost, Figure V-17 was generated for 1985 projections. Utility financing was assumed for a 20,000 TPD gasifier. As can be seen from the figure MBG gas price is \$4-9 /MMBTU. Competing fuel prices are estimated to be in the \$4-6/MMBTU range. Rough capital investment costs are 1.5 to 2.5 billion dollars, net operating cost around a hundred million. Therefore, average gas prices are \$5.50-\$7.00/MMBTU in 1985.

1975-1977 cost estimates for MBG are shown on Figure V-18 for smaller gasification systems. Gas costs range from \$2.81-\$5.34/MMBTU depending on the process and size.

Competing fuel prices and projections are normally projected linearly as shown on Figure V-19. In general it is assumed prices remain relative to each other. However, recent trends in fuel oil and natural gas prices are exponentially increasing. Therefore, linear projections are probably not valid from now through the 1980's, the period of facility

* "Detailed Cost Analysis of Coal Gasification Processes," J. T. Cobb, et. al., Fifth Annual International Conference on Coal Gasification and Liquification, August 1978.

THE BDM CORPORATION

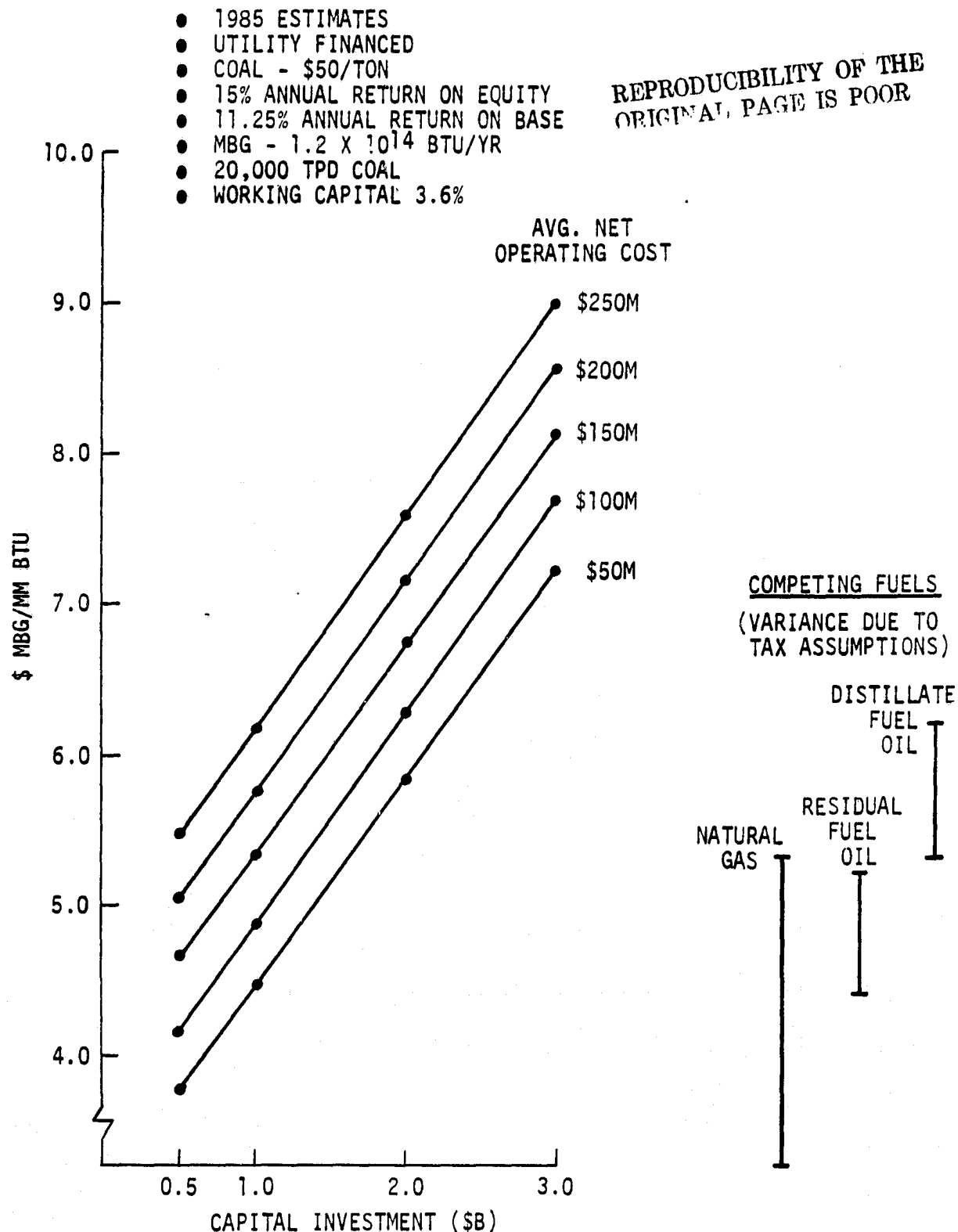


Figure V-17. Medium-BTU Gas Price as a Function of Capital Investment and Operating Cost

Estimate Number:	1	2	3	4	5	6	7	8
Process:	Winkler	Koppers-Totzek	Winkler	Koppers-Totzek	Koppers-Totzek	Lurgi	U-Gas	CE Entrained Bed
Factor	Original Estimate Date:	1977	1976	1977	1977	1976	1975	1975
Coal Properties		Sub-Bituminous			Bituminous			
Moisture, %	10	2			2	4.2	4.2	4.2
Sulfur, %	2.78	0.7	High	High	4.08	4.3	4.3	4.3
Coal Price, \$/ton	25	7.5	25	25	25	25	25	25
Coal Feed, MMTons/year	2.9	1.1	0.2	0.8	3.1	3.3	3.3	3.3
Gas Produced, 10 ¹² Btu/yr	40.7	15.7	3.7	11.4	56.5	39.2	59.8	58.5
Gas Quality	Cold, Clean Desulfurized	Cold, Clean Desulfurized	Cold, Clean Desulfurized	Cold, Clean Desulfurized	Cold, Clean Desulfurized	Cold, Clean Desulfurized	Cold, Clean Desulfurized	Cold, Clean Desulfurized
Net Operating Expense, \$MM/year	25.3	15.9	4.4	7.5	30.7	30.1	20.1	31.1
Total Plant Investment, \$MM	240.0	173.2	20.2	107.2	367.0	462.8	290.1	251.7
Type Facility	Central	Central	Individual	Central	Central	Central	Central	Central
Type Financing	Utility	Utility	Private	Utility	Utility	Utility	Utility	Utility
Gas Cost, \$/MM Btu (1977 Dollars)	3.35	3.31	3.99	3.84	3.03	5.34	2.81	2.97

Sources:

1. Economics of Current and Advanced Gasification Processes for Fuel Gas Production, Report No. EPRI-AF-244, Fluor Corp., July 1976
2. "Koppers-Totzek Economics and Inflation," D.M. Mitsak, et.al., Third Annual Conference on Coal Conversion, August 1976.
3. "Detailed Cost Analysis of Coal Gasification Processes," J.T. Cobb, et.al., Fifth Annual International Conference on Coal Gasification, August 1978.

Figure V-18. Costs for Medium-BTU Gasification Systems

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

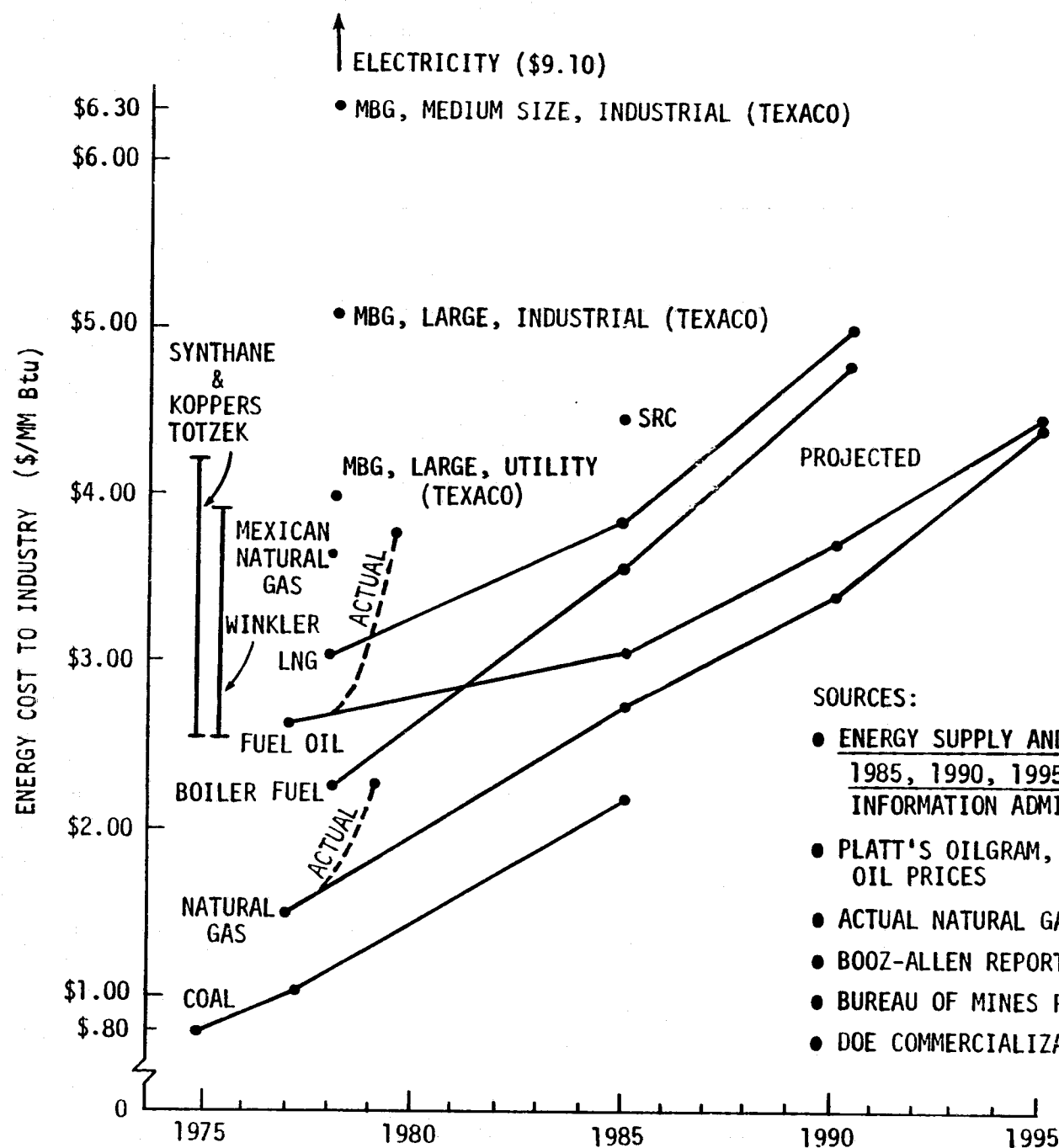


Figure V-19. Cost of Estimates of Various Coal Utilization Configurations vs. Conventional Industrial Fuel Prices

THE BDM CORPORATION

development. Large variations even exist in current prices between regions in the United States; for example, an agreement was recently reached with the Mexican government on purchasing five hundred million cubic feet of natural gas a day at \$3.62/MMBTU, significantly greater than \$2.25/MMBTU range in the region. Preliminary cost estimates give \$4.00/MMBTU for MBT processes. Electricity, a major competing energy form, is currently about \$9.10/MMBTU, significantly higher than other fuels but easier in handling and environmentally clean. Also electricity is necessary for machinery drives and lighting.

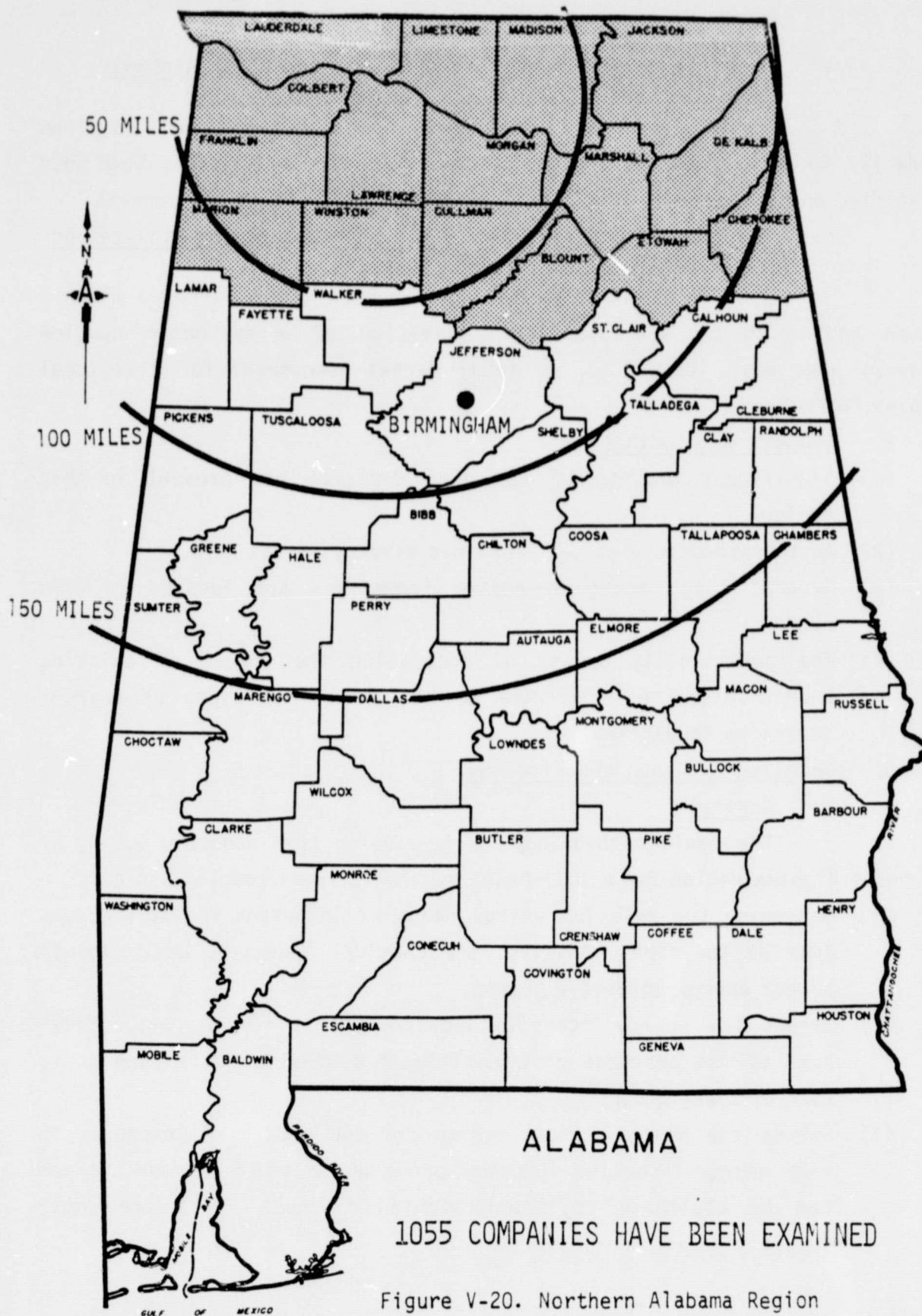
In summary, the following table provides estimates for MBG and competing fuels:

	(\$/MMBTU)	
	<u>1979</u>	<u>1985</u>
MEDIUM BTU GAS	\$2.50 - \$5.00	\$5.50 - \$9.00
NATURAL GAS	2.25 - 3.62	5.00 - 7.00
BOILER FUEL	2.40 - 3.00	5.00 - 6.50
ELECTRICITY	8.50 - 9.50	?

D. THE NORTH ALABAMA MARKET

1. Background and Purpose

The economic viability of a synthetic fuels complex is highly dependent on the specific siting of the facility. For example, it is probably not economically feasible to transport medium-BTU gas, one potential end product of a coal gasification plant, further than 100-150 miles from the point of origin. Therefore, an economic survey of a specific geographical area is essential to obtain data on the attractiveness of a synthetic fuels complex. The specific area chosen in this study is the North Alabama region, (See Figure V-20) which has several attractions from the standpoint of economical utilization of the products of a coal-based synthetic fuels complex. The purpose of this survey was to:



THE BDM CORPORATION

a. Identify Major Current Industries in the North Alabama Region and their Energy and Product Requirements

Current industry data has been obtained and compiled primarily for manufacturing plants. Industry energy requirements have been identified and amalgamated to ascertain regional synthetic fuels markets.

b. Identify Industries Which Could be Attracted to Utilization of Synthetic Fuels Complex Processes

Industries which currently are not in the Northern Alabama region and could be attracted to utilization of a synthetic complex products have been identified. A total market assessment for a regional complex has been performed.

2. Summary of Findings

- (1) Significant amounts of raw coal deposits are present in this region.
- (2) An infrastructure of gas pipelines already exists here.
- (3) Several large energy-intensive industries are located in this region.
- (4) The potentiality exists of increasing the number of existing energy-intensive industries or attracting new types of energy-intensive industries.

3. Detailed Approach and Findings

a. General

The basic methodology in developing this economic survey of the North Alabama region for a coal-based synthetic fuels complex was to:

- (1) Determine the relative energy needs of important industry groups such as the steel industry, the chemical industry, etc., and to select energy-intensive groups.
- (2) Assess the energy-intensive industry groups for the attractiveness of the products of a coal-based synthetic fuels complex to each of these groups.
- (3) Survey the North Alabama region for the number of companies in each energy-intensive industry group which would be most attracted to coal-based synthetic fuels if these fuels are cost-competitive and non-interruptible.

- (4) Identify industries not in this region which could be attracted by the products of a coal-based synthetic fuels complex.

b. Consumption of Energy by Different Industries

In order to narrow this survey to energy-intensive industries, it is first necessary to examine which industries are intensive utilizers of energy. One measure of energy consumption is the electrical requirement of broad industrial groups. Those data were presented in Figure V-7 for the ten largest industries consumers of electrical energy in this country.

c. Categorization of Industries by Potential Utilization of Coal-Based Synthetic Fuels

Figure V-10 previously summarized for key energy-intensive industries the energy demand schedules that affect the marketability of LBG (low BTU gas) or MBG (medium BTU gas), considering that continuous energy demands that permit operation of gasification facilities at or near capacity are favored because of the capital intensiveness of such facilities. In addition, this table summarizes the apparent technical suitability of LBG and MBG from coal for new and economical retrofit installations.

Clearly, Group I industries are the most promising candidates for successful application of MBG. This observation is reflected in Figure V-10, which shows that three key industries - petroleum refining, chemicals and basic steel account for most of the MBG market potential in each of the metropolitan areas.

Similarly, certain characteristics of Group II industries suggest that their potential demand for MBG would be incidental and site-specified*. For example, pulp mills would probably be excluded because of the remoteness of their locations and the fact that up to 90 percent of the steam load may be provided from captive fuels derived from forest product wastes. In some areas, paper mills, automobile tire plants, and some food processors could provide markets, but the scale of energy requirements for individual plant sites suggests that contributions to the market would be relatively small, except in certain areas of especially high concentration of specialized industrial activity such as Akron, Ohio.

THE BDM CORPORATION

The energy demands of Group III industries are characterized by extreme seasonality that is attributable to the relative importance of space heating in facilities of this type^{*}. Such seasonal fluctuations in demand make it unlikely that an MBG-producing facility could be operated at or near capacity if a Group III industrial consumer were among its principal MBG users. Although consumers within these industries could be incidental participants in the market for MBG, they would necessarily be subordinated to other users providing continuous demands. The amount of MBG sold to Group III consumers would thus be limited by the amount of load factor dilution that could be tolerated without unduly affecting MBG economics.

Generally, most straight-forward fuel applications in new installations could accommodate LBG or MBG if designed appropriately. In existing installations, however, the retrofit needed to accommodate LBG would be considerably more extensive than that required for MBG. In the opinion of many industrial fuel consumers, such an extensive retrofit for LBG would be prohibitively expensive, except perhaps where the switch is quite limited in scope.

Group IV industries are often remotely located and are subject to site-specific constraints that discourage generalizations on the suitability of MBG for these markets. However, such industries would be unlikely to appreciably affect the total market for gas from coal in metropolitan areas.

d. Large North Alabama Industries

A survey of 1050 industry plants in the 16 counties of the North Alabama region reveals a significant number of large complexes which are energy-intensive. The 19 plants in North Alabama which employ 1,000 or more people are listed in Figure V-21.

^{*} Market opportunities for Low and Intermediate BTU Gas from Coal, Stanford Research Institute, June 1978.

THE BDM CORPORATION

COMPANY NAME	LOCATION	NUMBER OF EMPLOYEES
1. GENERAL MOTORS SAGINAW STEERING GEAR DIVISION	ATHENS, LIMESTONE COUNTY	2,000
2. CHAMPION INTERNATIONAL	COURTLAND, LAWRENCE COUNTY	1,000
3. NICHOLSON FILE CO.	CULLMAN, CULLMAN COUNTY	1,000
4. MONSANTO CO.	DECATUR, MORGAN COUNTY	2,500
5. PRESOLITE, INC.	DECATUR, MORGAN COUNTY	1,000
6. THREE M CO., INC.	DECATUR, MORGAN COUNTY	1,500
7. UNIVERSAL OIL PRODUCTS, INC.	DECATUR, MORGAN COUNTY	1,000
8. GOOD YEAR TIRE AND RUBBER CO., INC.	GADSDEN, ETOWAH COUNTY	4,000
9. HEALTH-TEC, INC.	GADSDEN, ETOWAH COUNTY	1,000
10. REPUBLIC STEEL CORP.	GADSDEN, ETOWAH COUNTY	4,000
11. MONSANTO CO., INC.	GUNTERSVILLE, MARSHALL COUNTY	1,500
12. CHRYSLER CORP.	HUNTSVILLE, MADISON COUNTY	2,000
13. HUNTSVILLE MANUFACTURING CO., INC.	HUNTSVILLE, MADISON COUNTY	2,000
14. GTE AUTOMATIC ELECTRIC CORP.	HUNTSVILLE, MADISON COUNTY	4,000
15. SCI SYSTEMS, INC.	HUNTSVILLE, MADISON COUNTY	1,000
16. TELEDYNE BROWN ENGINEERING INC.	HUNTSVILLE, MADISON COUNTY	1,000
17. FORD MOTOR CO.	SHEFFIELD, COLBERT COUNTY	1,500
18. REYNOLDS METALS CO., INC.	SHEFFIELD, COLBERT COUNTY	1,500
19. GC LINGERIE CORP.	TUSCUMBIA, COLBERT COUNTY	1,000

Figure V-21. Large North Alabama Industries

THE BDM CORPORATION

e. Potential North Alabama Industrial Users of Coal-Based Synthetic Fuels

The number of facilities in the 16 counties of the North Alabama region which are members of the industrial groups most attracted to the medium-BTU gas which could be produced by a synthetic fuels complex is shown in Figure V-22.

GROUP NUMBER	INDUSTRY TYPE	NUMBER OF FACILITIES LOCATED IN NORTH ALABAMA
I	1. PETROLEUM REFINING*	0
	2. PRODUCTION OF CHEMICALS	25
	3. BASIC STEEL MANUFACTURING	3
II	1. RUBBER PRODUCTION	5
	2. LUMBER AND PULP	22
	3. PAPER	1
	4. FOOD PROCESSING	45
III	1. METAL FABRICATION	77
	2. MANUFACTURE OF ELECTRICAL EQUIPMENT	32
	3. OTHER MANUFACTURED MACHINERY	45
	4. CAN MANUFACTURING*	0
IV	1. NON-FERROUS METAL PRODUCTION	5
	2. BENEFACTION OF IRON ORE*	0
	3. GLASS MAKING	1

NOTE: THERE ARE 93 TEXTILE MILLS AND 51 CONCRETE PLANTS IN NORTH ALABAMA

Figure V-22. Number of Facilities in North Alabama

THE BDM CORPORATION

APPENDIX A AND B

Catalog of Coal Gasification Systems

LIST OF SYSTEMS

PART I: HIGH BTU COAL GASIFICATION PROCESSES

A-12 to A-36

1. Air Products Recycle Process	A-13
2. ATGAS/PATCAS	A-14
3. BIANCHI	A-15
4. BI-GAS	A-17
5. Chevron Gasification	A-18
6. CO ₂ Acceptor	A-19
7. Electrofluidic Gasification	A-20
8. Exxon Catalytic Gasification	A-21
9. Exxon Gasification	A-23
10. Garrett's Gasification	A-24
11. Gegas	A-25
12. Hydrane	A-26
13. Hygas	A-27
14. Liquid Phase Methanation (LPM)	A-29
15. Molten-salt	A-30
16. Multiple Catalyst	A-31
17. Solution Gasification	A-32
18. Sun Gasification	A-33
19. Total Gasification	A-34
20. Two Stage Fluidized Gasification	A-35
21. Union Carbide Agglomerating Ash for High BTU Gas	A-36

THE BDM CORPORATION

PART II: PROCESS FOR PRODUCTION OF MEDIUM-LOW BTU GAS	A-12 to A-105
1. Allis-Chalmers Kilngas System	A-38
2. Avco Arc-Coal Process	A-39
3. Babcox & Wilson-Dupont Entrained Flow Process	A-40
4. Bell Aerospace Inc. Entrained Process	A-41
5. British Gas Corporation Slagging Lurgi	A-42
6. C. E. Entrained Fuel Process	A-44
7. Coalex	A-46
8. Cogas	A-47
9. Combined Cycle-Babcock & Wilson	A-48
10. Combined Cycle-Foster & Wheeler	A-49
11. Consol Fixed Bed	A-50
12. Electric Arc	A-51
13. G.R.D. Gasification	A-52
14. H.R.I. Fluidized-Bed	A-53
15. H.R.I. Gasification (Squires)	A-54
16. Hydrogen From Coal Facility	A-55
17. I.C.I. Moving Burden	A-56
18. I.F.E. Two-Stage	A-57
19. I.G.I. Two-Stage	A-58
20. Kellogg Fixed Bed	A-60
21. Kellogg Molten Salt	A-61
22. Kerpely Producer	A-62
23. Koppers-Totzek (K-T)	A-63
24. Laser Irradiation Pyrolysis	A-64

THE BDM CORPORATION

25. Lurgi	A-65
26. Mauschka	A-67
27. Mountain Fuel Associates Entrained Process	A-68
28. Multiple Fluidized-Bed	A-69
29. Otto Rummel Slag Bath (Double Shaft)	A-70
30. Panindco	A-71
31. Pintsch Hillebrand	A-72
32. Philadelphia and Reading	A-73
33. Power-Gas	A-74
34. Power on Combined Cycle and Test Facility	A-75
35. Rapid, High Temperature	A-77
36. Riley-Morgan	A-78
37. Rocket Dyne Corporation's Entrained Process	A-79
38. Rochgas	A-80
39. Ruhrgas Vortor	A-81
40. Rummel Slag Bath	A-82
41. Soarberg-Otto Process	A-83
42. Shell-Koppers	A-84
43. Stirred Fixed Bed ("Morgas") Process	A-85
44. Stoic Two-Stage Gasifier	A-86
45. Submerged Coal Combustion	A-87
46. Synthane	A-88
47. Texaco Gasification	A-89
48. Thyssen Galocsy	A-90
49. Two-Step Coal Pyrolysis-Gasification Process	A-91

THE BDM CORPORATION

50. TRW Entrained Process	A-92
U-Gas	A-93
U.G.I. BTU Water Gas	A-94
53. Union Carbide Agglomerating Ash for Low-Medium BTU Gas	A-95
54. Washington Fuel Cell	A-96
55. Wellman-Galusha	A-97
56. Well Man-Incandescent Two-Stage Gasifier	A-99
57. Westinghouse Low-BTU Process (Fluidized Bed)	A-100
58. Winkler	A-102
59. Wilputte Producer	A-104
60. Woodall-Duckham/Gas Integral	A-105

THE BDM CORPORATION

Appendix B LISTING OF MODELS AND ANALYTICAL METHODOLOGIES

PART I: STEADY STATE FLOW SHEET SIMULATION	B-3 to B-43
1. AGPSS	B-3
2. ASPEN	B-4
3. ChemE Simulator	B-5
4. Chemical Engineering Simulation System (CHESS)	B-6
5. Chemical Process Simulator	B-7
6. CHEMOS	B-8
7. Computer Aided Design Flow-Sheeting Program Design (SUCES)	B-9
8. CONCEPT	B-10
9. DESIGN	B-11
10. EBP-II	B-12
11. Energy Balance for Dual Purpose Power Plant (ENGBAL)	B-13
12. EXEC	B-14
13. FAST	B-15
14. FLOWSIM	B-16
15. FLOWTRAN	B-17
16. General Engineering and Management Computation System (GEMCS)	B-18
17. General Process Simulator (GPS II)	B-19
18. GPFS	B-20
19. MBP-II	B-21
20. MOSES (Modelling System for Engineering Studies)	B-22
21. MPPM	B-23
22. PATT	B-25

THE BDM CORPORATION

23.	PROCESS	B-26
24.	Process Analysis System	B-27
25.	Process Design Analysis, Phillips Petroleum Co. Program Package I (PDA)	B-28
26.	Process Optimization System (PROPS)	B-29
27.	Process Simulation Executive (PSX)	B-30
28.	Simulation Program PROCESS	B-31
29.	Program for Chemical Plants Simulation (SIMUL-UNT)	B-33
30.	Rhone-Poulenc Industries Program Package	B-34
31.	RUMBA	B-35
32.	SEPSIM	B-36
33.	Steady State Simulation System	B-37
34.	SIMUL	B-38
35.	Simulator for Process Analysis and Design (SPAD)	B-39
36.	SYMBOL and SYMBOL-WITH-BOUNDS	B-40
37.	SYNTHA II	B-41
38.	SYNTHA III	B-42
39.	TISFLO	B-43

THE BDM CORPORATION

PART II: GASIFIER SIMULATIONS

B- 5 to B-52B

- | | |
|-------------------------------------------------------|-------|
| 1. Coal Gasifier Simulator | B-45 |
| 2. Dynamically Modeled Coal Gasification Simulator | B-46 |
| 3. Fixed Bed Coal Gasification Simulator | B-47 |
| 4. Fluidized Bed Gasifier | B-48 |
| 5. General Gasifier Modeling | B-49 |
| 6. Modeling and Analysis of Moving Bed Coal Gasifiers | B-50 |
| 7. 1 DICO, PCGC-1 | B-52 |
| 8. Complex Chemical Equilibrium Model | B-52A |

THE BDM CORPORATION

PART III: COST ESTIMATIONS AND ECONOMIC SIMULATIONS	B-54 to B-70
1. COST	B-54
2. Chemical Engineering Economic Package (CHEEP)	B-57
3. Economist	B-58
4. Guthrie Modular Approach (Manual TECHNIQUE)	B-59
5. Heat Exchanger Pricing Program	B-60
6. PCOST	B-62
7. PEPCOST - Computer Program to Estimate Capital and Production Costs	B-63
8. Preliminary Economics Computer Program (E-301 Program)	B-64
9. Pressure Vessel Cost Estimating	B-65
10. Price and Delivery Quoting Service for Chemical Process Equipment (PDQS)	B-66
11. Project Valuation and Estimation System (PROVES)	B-67
12. Richardson Rapid System (Manual Technique)	B-68
13. Shell and Tube Heat Exchanger Cost Estimation, Program 5066 (Phillips Petroleum Co. Program Package 1)	B-69
14. Wastewater Treatment Plant Cost Estimating	B-70

THE BDM CORPORATION

PART IV: ECONOMIC AND FINANCIAL EVALUATION

B-72 to B-89

1. A Review of Cost Estimation in New Technologies. Implications for High Energy Process Plants. B-72
2. Cash Flow B-73
3. Cash Flow Analysis (CFA) B-74
4. Cash Flow Forecast B-75
5. Chemical Process Screening Program B-76
6. Discounted Cash Flow Calculations B-77
7. Discounted Rate of Return on Investment B-78
8. Economic Evaluation of Municipal Water Supply and Waste Water Disposal Including Considerations of Seacoater Distillate and Wastewater Removal B-79
9. Economic Evaluation of Process Operations and Capital Costs B-80
10. Guidelines for Economic Evaluation of Cost Conversion Processes B-81
11. Planning and Analysis in Uncertain Situations (PAUS) B-83
12. P.R.F. - A Discounted Cash Flow Program for Calculating the Production Cost of the Product from a Process Plant B-84
13. Profitability Estimation Using Probabilistic Data Inputs B-85
14. Profit (Interactive) B-86

References

B-87 to B-89

THE BDM CORPORATION

APPENDIX A
CATALOG OF COAL GASIFICATION
SYSTEMS

Page intentionally left blank

THE BDM CORPORATION

1. TITLE: AIR PRODUCTS RECYCLE PROCESS

OWNER/DESIGNER: Air Products and Chemicals, Inc., Allentown, Pa.

DESCRIPTION: This process produces a high-Btu pipeline gas without requiring shift conversion and methanation by separating methane from the raw gas produced in the gasifier at low temperatures. In addition, the mixture of hydrogen and carbon monoxide are recycled to the gasifier to produce additional methane and improve the heat input to the reactor. The off-gas, containing a mixture of carbon dioxide and monoxide, methane, hydrogen sulfide and hydrogen, is then processed through a char-removal step by which the char is recycled to the first stage of the gasifier. Once elimination of CO_2 , H_2S and water is accomplished, the synthesis gas stream is cryogenically separated to obtain a methane product stream. Similarly, the CO and H_2 stream is heated and recycled to the second stage of the gasifier where it reacts with products from the first stage (i.e., coal, steam and synthesis gas) for producing additional methane and synthesis gas. A benefit of this process is that it reduces coal and oxygen requirements while requiring increased amounts of steam compared to those processes utilizing shift and methanation of synthesis gas.

STATUS: This process is still in the early stages of development. Details are scanty. (1976).

THE BDM CORPORATION

2. TITLE: ATGAS/PATGAS

OWNER/DESIGNER: Applied Technology Corporation

DESCRIPTION: Crushed and dried coal is injected into a molten iron bath through steam lances. Through these lances, located at the iron-bath surface, oxygen is introduced. Coal dissolves in the molten iron where the volatiles crack and are converted into carbon monoxide and hydrogen. With the oxygen and steam, the fixed carbon melts, producing additional carbon monoxide and hydrogen. Caking, high-ash and high-sulfur coals can be utilized.

Sulfur of the coal migrates to a lime slag floating on the molten iron and forms calcium sulphide. The slag is constantly being withdrawn and desulfurized with steam to yield elemental sulphur and desulfurized slag. The raw gas from the gasifier can be used as intermediate Btu fuel gas (315 Btu/scf) or as a synthesis gas to produce other organic compounds (PATGAS PROCESS). In the ATGAS PROCESS (2,500°F and 50 psi), the medium-Btu off-gas from the gasifier is subjected to shift conversion, purification, methanation and compression to produce an S.N.G. product (940 Btu/scf). All types of coal can be gasified in this process.

STATUS: This process has been under laboratory investigation since 1967. Up to now, the process has been demonstrated in short duration runs (30-40 minutes) in a 2 foot internal diameter gasifier. Plans for further development intend to utilize larger gasifiers to demonstrate possible long duration operation. Most of the technology pertinent to this process currently exists as discrete commercial steps in the iron and steel industry. However, the combination of these steps remains to be demonstrated on a large scale. EPA is evaluating the feasibility of the process for utilization of high sulfur coals within E.P.A. pollution standards. (1976)

THE BDM CORPORATION

3. TITLE: BIANCHI

DESCRIPTION: Pulverized coal entrained in a steam-oxygen stream is injected tangentially into the center of a vortex chamber operating at 150-350 psi and at temperatures below 1,700°F. The ash is entrained in the product gas stream which after ash removal in dust cyclones has a calorific value of 440 Btu/scf which is suitable for catalytic methanation to pipeline quality gas.

STATUS: A pilot was built in France to evaluate the production of pipeline gas from lignite. No details are available on the current status of the process. (1976)

THE BDM CORPORATION

The raw gas (contained carbon monoxide, carbon dioxide, hydrogen, water, hydrogen sulfide, and methane) is separated in a char cyclone and passes through a scrubber for additional cooling and cleaning. The clean gas, along with the desired amount of moisture, is sent to a carbon monoxide shift converter to establish the proper ratio of carbon monoxide and hydrogen required in the methanation process.

STATUS: Development work has proceeded from batch autoclave studies, through continuous flow experiments in a 5lb./hour externally-heated reactor, to operation of a 100lb./hour internally fixed process and equipment development unit (PEDU). A pilot plant in Homer City, Pa., has been in operation intermittently since 1977. (1978)

4. TITLE: BI-GAS

OWNER/DESIGNER: Bituminous Coal Research, Inc.

DESCRIPTION: The BI-Gas process is a two-stage, high-pressure, oxygen-blown system using pulverized coal and steam in an entrained flow. All types of coal can be gasified without prior treatment, since the process uses an entrained rather than a fixed or fluidized-bed system. In the BI-Gas process, a high yield of methane is obtained directly from coal, minimizing subsequent processing of the product gas.

Raw coal is first pulverized so that approximately 70 percent will pass through 200-mesh. The coal, mixed with water, is fed to a cyclone where the solids are concentrated into a slurry. Coarse underflow from the cyclone is sent to a wet grinding mill for further crushing. The slurry is further concentrated in a thickener and centrifuge, repulped and mixed with flux to generate the desired concentration, and fed to the downstream high-pressure feed system.

A high pressure slurry pump picks up the blended slurry and transports it under pressure to a steam preheater. The hot slurry is then contacted with hot recycle gas in a spray dryer for nearly instantaneous vaporization of the surface moisture. The coal is conveyed to a cyclone at the top of the gasifier vessel by a stream of water vapor and inert recycle gas, as well as additional recycled gas from the methanator. The coal is separated from the hot recycle gas in the cyclone and the coal flows by gravity to the gasifier.

The coal enters the gasifier through injector nozzles near the throat which separates Stage 1 and Stage 2. Steam is introduced through a separate annulus in the injector. The two streams combine at the tip and join the hot synthesis gas rising from Stage 1. A mixing temperature of about 2,200°F is attained rapidly and the coal is converted to methane, synthesis gas, and char. The raw gas and char rise through Stage 2, leave the gasifier at about 1,700°F, and are quenched to 800°F by atomized water.

THE BDM CORPORATION

5. TITLE: CHEVRON GASIFICATION

OWNER/DESIGNER: Chevron Research Company

DESCRIPTION: The process produces high-Btu gas from a wide range of organic feeds such as lignite, organic waste materials, wood and essentially any organic material containing some hydrogen and at least 10 wt. % oxygen with 25 wt. % oxygen preferred. The organic material is reacted with steam at 50-800 psi. (preferably 300-800 psi.) and 1,200-1,400°F in the presence of an alkali-metal catalyst (e.g., K_2CO_3). The high-Btu gas is produced under these conditions by the catalytic steam-reforming of the products of degradation of the feed.

STATUS: U.S. Patents 3,775,072 and 3,759,677 described by R. J. White, have been assigned to Chevron Research Company. Details on development of the process are not available. (1976)

THE BDM CORPORATION

6. TITLE: CO₂ ACCEPTOR

OWNER/DESIGNER: Consolidation Coal Company

DESCRIPTION: In the CO₂ Acceptor process, lime particles are injected into the fluidized gasifier; this liberates heat by reaction with carbon dioxide to form calcium carbonate. To close the cycle, the calcium carbonate is converted back to lime in the fluidized-bed regenerator. The heat of calcination is supplied by burning residual fuel char from the gasifier with air in the regenerator fluidized-bed.

The process operates at about 150 psi and the energy for air compression is obtained by expansion of the regenerator off-gas. The steam necessary to operate the process is also generated by heat exchange with the regenerator off-gas and the gasifier off-gas.

Lignite and sub-bituminous coals are the preferred feeds to the process because of their high reactivity; the gasification temperature is sufficiently low to avoid solid deposits and particle agglomeration with a lignite whose ash exceeded 8 percent alkali content (as sodium and potassium oxides).

The product gas leaving the gasifier must be subsequently purified, methanated, compressed, and dehydrated to produce specification pipeline gas.

STATUS: The process development was carried to the 40 tpd pilot plant stage. At this time, the test program has been completed and the pilot plant has been shut down. (1978)

THE BDM CORPORATION

7. TITLE: ELECTROFLUIDIC GASIFICATION

OWNER/DESIGNER: Department of Chemical Engineering and Engineering Research Institute
Iowa State University

DESCRIPTION: An electrofluidic reactor utilizes a fluidized-bed of conducting particles which is heated by passing an electrical current through the bed. The bed itself serves as a resistor between electrodes placed in contact with the bed. Since heat is generated directly within the bed, the device is useful for carrying out reactions which require substantial energy inputs and are favoured by high temperatures. Reacting steam and coal char in the reactor produces a wide range of hydrogen-carbon monoxide mixtures, as well as mixtures containing methane, suitable for up-grading by methanation to SNG.

STATUS: Both a 4" diameter batch reactor and a 12" diameter continuous reactor have been successfully operated. The Institute of Gas Technology has undertaken to integrate this process with the pilot plant testing of its HYGAS process' electrogasifier. No further information is available at this time. (1976)

THE BDM CORPORATION

8. TITLE: EXXON CATALYTIC GASIFICATION

OWNER/DESIGNER: Exxon

DESCRIPTION: In the Catalytic Coal Gasification process, carbon monoxide and hydrogen are recycled to a reactor to keep the CO/H₂ content as high as possible thus forcing the net products of the gasification reactions to be CO₂ and CH₄. The recycle rate is set such that there is no net yield of CO and H₂ in the gasifier.

Coal entering the system is impregnated with a recovered makeup catalyst prior to entering the reaction vessel, where the coal is gasified with steam at 1200° to 1400°F in the presence of equilibrium steam. The reactor product gas is purified and separated into a methane or SNG final product and a CO/H₂ fraction for recycle. The steam and recycled CO/H₂ are preheated to about 150°F above gasification temperatures prior to injection into the gasifier to balance system heat loss.

Char/ash residue containing catalyst is removed from the gasifier. The catalyst is recovered by water through a counter-current leaching operation. It is estimated that up to 90 percent of the carbonate may be reclaimed in this manner. Some catalyst reacts with coal ash to form an insoluble potassium aluminosilicate, with about 5 percent weight of coal feed estimated lost in the insoluble form. The recovery of the remaining potassium by routes such as acid wash of char is currently being investigated.

Advantages of the Catalytic SNG process are:

- o Pretreatment is not required for caking coals.
- o The need for oxygen or other means of providing high level heat directly in the gasifier is eliminated.
- o Gasifier temperatures are reduced.
- o Shift and methanation steps are eliminated.
- o Potentially higher thermal efficiency than that of thermal coal gasification processes is possible because of reduced need for high level heat input and greatly reduced heating and cooling of gas streams.

THE BDM CORPORATION

STATUS: Bench scale information is being collected to gather scale-up information. There was a simultaneous feasibility study being performed by Exxon Research and Engineering Company at Florham Park, New Jersey, to estimate the costs of conversion of an existing pilot plant, as opposed to new construction of a grass roots plant. Plans for the development of a process development unit had been initiated. Operation of a pilot plant was estimated for the middle of 1981. (1978)

THE BDM CORPORATION

9. TITLE: EXXON GASIFICATION

OWNER/DESIGNER: Esso Research and Engineering Company

DESCRIPTION: Coal is reacted with steam in a fluidized-bed gasifier at 1,500-1,700°F. To provide the necessary heat, a stream of circulating char is withdrawn from the gasifier and partially burned with air in a char heater to raise its temperature. The heated char is returned to the gasifier after separation from the flue gas. The product gas is a medium-Btu gas suitable for methanation to SNG. As a high-Btu gasification process Exxon's route is unique in that air is used rather than the oxygen most other processes use, thus eliminating the need of an oxygen plant. All types of coal can be gasified.

STATUS: A 0.5 ton per day integrated pilot plant has been in operation at Baytown for many years. Plans for a 500 TPD pilot plant was announced, but construction of the plant has not been defined due to rising costs and competition for financing from other projects. (1976)

THE BDM CORPORATION

10. TITLE: GARRETT'S COAL GASIFICATION

OWNER/DESIGNER: Garrett Research and Development Company and
Island Creek Coal Company

DESCRIPTION: This process utilizes a low-temperature pyrolysis step to optimise production of liquid fuels. For high yields of methane-rich gas, the coal feed is subjected to a rapid, high temperature pyrolysis in the reactor.

Pulverized coal is fed to the pyrolysis reactor with a recirculating stream of hot char. This hot char is from a separate, air-blown char heater which exhausts the nitrogen-rich gas produced as a flue gas. The hot char from the heater circulates to the pyrolyzer and provides the heat for the pulverized-coal pyrolysis. The pyrolysis gas is separated from entrained char in a series of cyclones and is then sent to purification, shift and methanation to upgrade the gas from its raw-state HHV of 600-650 Btu/scf to pipeline quality. The product char is a fine, highly reactive fuel suitable for combustion in a power-generation station. The calorific value of the product char can be significantly higher than that of the coal feed.

STATUS: Garrett originally tested and successfully evaluated this process in a 3.6 tpd pilot plant. Plans for a 250 TPD demonstration plant to be located near a power utility to be selected have been made. Operation of the commercial-scale pyrolysis reactor has been simulated with the operation of a continuous 3 pound per hour laboratory-scale reactor which had the same configuration as the projected commercial unit except that its heat source was electrical. Results have indicated yields of pipeline-gas equivalents ranging from 4,500 scf/ton of coal at 1,500°F - 7,500 scf/ton (D.A.F. basis) at 1,700°F, depending on coal type. Commercial-scale operation should yield an additional 1,000 scf/ton at 1,700°F of pipeline-gas equivalent by recycling the tar produced in the pyrolysis step to the reactor for further cracking. (1976)

THE BDM CORPORATION

11. TITLE: GEGAS

OWNER/DESIGNER: General Electric Research and Development Centre

DESCRIPTION: The process employs a moving fixed-bed gasifier, however, trouble is experienced with caking coals. To overcome this problem, inert bulk diluting agents such as silicon carbide or coal ash are utilized, thus increasing mass-flow through the gasifier. An extrusion process is used for coal-feeding and off-gases are cleaned of hydrogen sulphide using liquid selective membranes. A methanation step is required to up-grade the raw gas to pipeline quality.

STATUS: Preliminary tests have been completed in a 50 lb. per hour unit. General Electric is seeking partners for erection of a demonstration plant. (1976)

THE BDM CORPORATION

12. TITLE: HYDRANE

OWNER/DESIGNER: U.S. Bureau of Mines, Pittsburgh Energy Research Center

DESCRIPTION: Crushed raw coal is fed to a two-zone hydrogenation reactor operated at 1,000 psi and 1,650°F. In the top zone, the coal falls freely as a dilute cloud of particles through a hydrogen-rich gas containing some methane from the lower zone. About 20% of the raw-coal carbon is converted to methane, causing the coal particles to lose their volatile matter and agglomerating characteristics. The coal is now essentially a char. This char falls into the lower zone where hydrogen feed-gas maintains the particles in a fluidized state and also reacts with about 34% more of the carbon to make methane. The product gas exits from the center of the reactor and is cleaned of entrained solids and some unwanted gases. After clean-up, methanation of the small amount (2 to 5%) of residual carbon monoxide gives a pipeline-quality, high-Btu gas. Char from the lower zone of the hydrogasifier is reacted with steam and oxygen to generate the needed hydrogen.

STATUS: In bench-scale testing, a 10 lb./hour integrated unit has demonstrated the feasibility of the process. Results indicate that high-volatile bituminous coals can be fed directly to the gasifier without caking and agglomerating, thereby eliminating expensive pretreatment. Also, 95% of the methane in the final SNG product is made in the hydrogasification reactor from the raw coal directly by treatment with hydrogen. This scheme results in high thermal efficiency (78%). Scale-up to a 24 TPD pilot is planned. (1976)

13. TITLE: HYGAS

OWNER/DESIGNER: Institute of Gas Technology

DESCRIPTION: The HYGAS generator is a single, large pressure vessel enclosing three discrete reaction stages plus a drying chamber. The three enclosed reactors are dense-phase fluidized beds; the drying chamber uses an entrained-flow reactor planned for minimum residence time.

Pretreated coal is slurried with light oil which is produced as a by-product in the process. The slurry is then pumped to 1,000 - 1,500 psi and injected into the top of the hydrogasifier where oil evaporates at 600°F and is subsequently recovered for use.

In hydrogasification, the carbon-hydrogen reaction is promoted to produce methane exothermally. This heat is used to decompose steam on carbon to produce additional hydrogen. In the HYGAS hydrogasifier, two stages are used to achieve the above reactions. Dry coal particles at about 600°F from the slurry drying section flow by gravity through a dipleg into a lift pipe. The lift pipe serves as the first stage of hydrogasification. Here, a dilute phase contact occurs between the coal or pretreated char and the gases from the second stage. The gases are at approximately 1,500°F. The gas lifts the solids to the gas-solid disengaging section. As the dried coal is lifted, it is flash heated in the presence of hydrogen to 1,200° - 1,300°F, and converts approximately 20% of the coal to methane.

The partially gasified char flows into the second stage hydrogasification section and is contacted with the H₂-rich gas from the steam-oxygen gasifier. This stage is a dense-phase, fluidized-bed reactor operating at 1,600° - 1,700°F. Here, methane is formed simultaneously with the H₂ and CO produced by the steam-carbon reaction. Approximately 25% more of the coal is converted, thus 45-50% of the total feed coal is converted by hydrogasification reactions. In this stage, with steam present,

THE BDM CORPORATION

any rise in temperature speeds up the endothermic steam-char reaction; a temperature drop slows down the reaction. The hot gases rise to the first stage and to the dryer, where much of the heat is used to vaporize and dry the feed coal.

The partially depleted coal char leaving the second stage hydrogasification zone is used to produce hydrogen in the steam-oxygen gasification section. The steam and high purity oxygen convert the char into hydrogen and carbon oxides at temperatures up to 1850°F. Ash is discharged from this stage without being slagged. The ash is discharged into a tank where water is added to make a slurry, which is then depressurized. The ash is recovered by filtering and the water is recycled. The process temperature is approximately 1160°F PSI.

STATUS: A conceptual design for a commercial-size plant (250 million scfd) for the HYGAS process is now being designed. (1978)

A 8 TPD pilot plant has been in operation since 1971, producing gas at 370 Btu/scf, and 45,000 scf per ton of coal is produced.

THE BDM CORPORATION

14 TITLE: LIQUID PHASE METHANATION (L.P.M.)

OWNER/DESIGNER: American Gas Association and Office of Coal Research

DESCRIPTION: The process is suited to the conversion of gas containing high concentrations of carbon monoxide and hydrogen (15-20% CO, 45-60% H₂) into methane (CH₄) by affecting the heterogeneously-catalysed reaction of the feed gases in the presence of an inert liquid phase which absorbs the large exothermic heat of reaction as both sensible heat and as latent heat by vaporization.

In the process, the inert liquid (e.g., mineral oil, C₁₅ to C₂₁) is pumped upward through the reactor at a velocity sufficient to both fluidize the catalyst and remove reaction heat. The synthesis gas is passed concurrently upward through the reactor where it is converted to a high-concentration methane stream.

STATUS: The project's program was divided into three phases: Bench-scale unit, Process Development Unit (P.D.U.), and Pilot Plant.

Future plans for the L.P.M. process included studying the use of the system to effect both shift and methanation reactions simultaneously. (1976)

THE BDM CORPORATION

15 TITLE: MOLTEN-SALT

OWNER/DESCRIPTION: M. W. Kellogg Company

DESCRIPTION: Crushed (12 mesh), dried coal is picked up from lock hoppers by a preheated steam-oxygen stream and fed into the molten-salt gasifier. Recycled sodium carbonate is fed to the gasifier along with the coal. Coal-steam reaction is catalyzed by the molten salt contained in the reactor. A gas free of tars is produced at a sufficiently low temperature so that appreciable methane production can also take place.

A bleed stream of molten carbonate containing the coal ash in solution is withdrawn from the bottom of the gasifier. It is contacted with water to dissolve sodium carbonate. Ash is separated by filtration.

Sodium carbonate solution is carbonated to precipitate bicarbonate. The bicarbonate is filtered out and calcined to restore carbonate which is then recycled to the gasifier.

Raw gas leaving the gasifier at 1,700°F is passed through the heat recovery section. Any entrained salt is recovered. The raw gas is then shifted, purified, saturated and dehydrated to produce pipeline-quality gas.

STATUS: Because of problem arising from the corrosive nature of the salt the original testing of the process was discontinued. Further research has produced a non-corrosive alumina reactor lining which overcame the corrosive problem and incorporated the use of a single reactor vessel. The process was then planned to be tested in a process development unit ten times the size of earlier vessels. (1976)

THE BDM CORPORATION

16 TITLE: MULTIPLE CATALYST

OWNER/DESIGNER: College of Engineering, Natural Resources
Research Institute, University of Wyoming

DESCRIPTION: This is a method for the direct production of methane from coal and steam with the methanating-catalyst bed placed in the middle of the reactor and heated to the desired temperature (1,200-1,300°F) by a Lindberg furnace. The temperature is monitored by thermocouples located in the thermo-well inside the reactor. The methane-rich product gas passes through a motor valve which allows the pressure (1,000 psi) to be controlled. The end product is a high-Btu gas of 850 Btu/scf after purification.

STATUS: Development effort on the direct methanation process consisted primarily of batch-type tests at the bench scale level. Fifty-five different catalysts were listed in runs from 1 to 30 hours in duration. Before larger-scale continuous operation is successful, it is recommended that a better catalyst system be developed. A possible solution which promises to be most effective is a combination of an alkali carbonate such as potassium carbonate, and a nickel catalyst. (1976)

THE BDM CORPORATION

17 TITLE: SOLUTION GASIFICATION

OWNER/DESIGNER: Stone and Webster Engineering Corporation

DESCRIPTION: Coal is slurried in a solvent; then a two-step treatment with hydrogen solubilizes the coal and produces pipeline-quality gas without an explicit methanation step. No oxygen is required in the process. The process treats coal as a basic hydrocarbon in which the hydrogen content is increased from 5% in the raw material to 25% in the methane product. Hydrogen for the process is made by reforming part of the product methane with steam. A range of coal types can be used.

STATUS: This process has been tested in bench-scale runs. A study requiring conceptual design including estimates of yields for a complete commercial plant for processing about 35,000 tons per day of coal to produce some 600 million in feet per day of high-Btu pipeline gas has been undertaken. (1976)

THE BDM CORPORATION

18 TITLE: SUN GASIFICATION

OWNER/DESIGNER: Sun Research and Development Company

DESCRIPTION: Coal particles are oxidized by molten sodium sulphate in an exothermic reaction. The coal is converted to carbon monoxide, hydrogen and other gaseous products by oxidation of coal with or without steam, by molten sodium sulphate at 1,740-2000°F. The sodium sulphide, produced by the reduction of sodium sulphate, is oxidized with an oxygen source to sulphate for recycling to the gasifier. The moisture in the coal increases the hydrogen to carbon monoxide ratio in the product gases. The exothermic reaction results in almost complete gasification of the coal, minimizes gas flow, reduces capital investment, and results in less corrosion of the oxide refractories used as reactor linings. The raw gas is suitable for upgrading to pipeline quality.

STATUS: Sun Research and Development Company is the holder of U.S. Patent 3,770,399 pertaining to this process. Details of development work on the process are not available. (1976)

THE BDM CORPORATION

19 TITLE: TOTAL GASIFICATION

OWNER/DESIGNER: Total Energy Corporation

DESCRIPTION: The process employs two integrated gasifiers. Coal is fed to both gasifiers. In the first gasifier, carbon monoxide is formed which is sent to a hydrogen generator (shift reactor) where carbon monoxide and steam react to form hydrogen. The hydrogen stream is sent to the second gasifier where hydrogasification of the coal feed occurs under conditions minimizing carbon monoxide formation and optimizing methane production. The temperature in the hydrogasifier is controlled by an indirect heat exchanger rather than by the introduction of steam. Thus, the process requires only one source of raw materials -- coal. Steam for reforming is raised by process heat.

The methane-rich off-gas is suitable for upgrading to pipeline quality.

STATUS: Still in bench model stage of development. (1976)

THE BDM CORPORATION

20 TITLE: TWO STAGE FLUIDIZED GASIFICATION

OWNER/DESIGNER: Midlands Research Station, United Kingdom

DESCRIPTION: Coal is subjected to hydrogenation in two stages: a rapid reaction at 800-850°C and a slower reaction at 900-950°C, at a pressure of about 750 psi. The char produced then passes to a fluidized-bed gasifier operating at 1,900°F, producing a lean gas which is subsequently upgraded by catalytic methanation to pipeline quality.

STATUS: A pilot plant design has been produced by modelling for a 4 million scfd of gas plant utilizing a gasifier operating at 1,050°C and 450 psi. (1976)

THE BDM CORPORATION

21 TITLE: UNION CARBIDE AGGLOMERATING ASH FOR HIGH BTU GAS

OWNER/DESIGNER: Union Carbide Corp., Battelle Memorial

Institute, Columbus, Columbus Laboratories

DESCRIPTION: This system combines two fluidized bed systems, a combustor and a gasifier, connected by an agglomerating ash circuit. The system accepts all types of coal without pretreatment. The coal is pulverized to -35 mesh, injected into a fluidized bed of hot ash agglomerates, and flows through the bed where coal-steam gasification occurs. The end-product, char, concentrates at the top of the bed. The hot-ash agglomerate from the combustor, enters the gasifier at 2,000-2,100°F at a point below char-level and descends through the reaction and pre-heat zones where it is cooled to 1,000°F. It then enters a stripping zone where entrained coal is removed, and stripped agglomerates are collected for pumping to the combustor. Char is withdrawn from the top of the gasifier continuously, and reheated to 2,100°F with air in the combustor for recycling to gasifier.

Hot flue gases from the combustor bed are processed to recover heat, remove SO₂, and regain compression energy through the use of an expander. Raw gas of approximately 300 Btu/scf is produced by the gasifier bed at a temperature of 1,800°F. It is processed to recover heat, remove particulates, ammonia, and sulphur compounds. The clean gas product can be used to produce pipeline quality high-Btu gas (950 SCF/scf) by shift and methanation. It can also be used directly to fuel turbines and boilers for electric power generation.

STATUS: A process development unit, producing 800,000 scfd of synthesis gas from 25 TPD of coal was to be in operation in West Jefferson, Ohio, and run by Coalcon, a Chemico and Union Carbide joint venture. (1976)

THE BDM CORPORATION

PART II
PROCESSES FOR PRODUCTION OF MEDIUM-LOW BTU GAS

THE BDM CORPORATION

1. ALLIS-CHALMERS KILNGAS SYSTEM

OWNER/DESIGN: Allis-Chalmers

DESCRIPTION: Air and steam are injected into a rotary kiln through ports located in a devolatilization and gasification zone. Coal is fed into one end of the kiln and ash is removed from the other. The product gas is then quenched with water to remove tars and particulates, and passed through a Stretford sulfur removal system to yield clean low Btu gas.

STATUS: The Kilngas system has been under private development at the Allison-Chalmers Process Research Test Center at Oak Creek, Wisconsin since 1971. Pilot plant facilities there have operated at up to sixty TPD of coal. The State of Illinois at the beginning of this year approved funding of a Wood River demonstration plant for the technology in Madison County, Illinois (1979).

THE BDM CORPORATION

2. TITLE: AVCO ARC-COAL PROCESS

OWNER/DESIGNER: AVCO Corporation, Everett, Massachusetts

DESCRIPTION: This process has been under investigation by AVCO for a number of years. Studies have been undertaken by the Dravo Corporation and Pennsylvania State University to determine the commercial feasibility, and technical requirements for the production of acetylene using this process. The Dravo Corporation's evaluation was based on a production rate of 300 million lbs. per year of acetylene, and included facilities for recovery of by-products like carbon black, HCN, char, low-Btu fuel gas, and several forms of sulphur.

STATUS: It is believed that investigation of this process is continuing. Research has been conducted under the auspices of the Office of Coal Research, and interim reports of investigations are available. (1976)

THE BDM CORPORATION

3. TITLE: BABCOCK & WILCOX - DUPONT ENTRAINED FLOW PROCESS

OWNER/DESIGNER: B&W/DuPont

DESCRIPTION: Coal and steam are fed to a cylindrical gasifier incorporating primary and secondary reaction chambers operating at atmospheric pressure under slagging conditions. Coal, steam and oxygen react to form a 270 Btu/scf synthesis gas.

STATUS: This technology is considered to be outdated by more recent developments. Historically, however, following pilot-scale testing by the U.S. Bureau of Mines in the late 1940's, Babcock & Wilcox constructed a small commercial-scale, 5 ft. diameter gasifier of similar design for E. I. DuPont at Belle, West Virginia. A 15 ft. diameter unit was later built at Belle and has been operated by DuPont since 1951. This latter plant, at a feedstock rate of 17 TPH of coal, produces 25 million scfd of 275 Btu/scf gas.

Some tests under pressures of 100 and 300 psi were conducted on tests reactors B&W installed at Morgantown, but these were run on a batch basis only, at rates up to 12 TPD coal. (1978)

THE BDM CORPORATION

4. TITLE: BELL AEROSPACE INC. ENTRAINED PROCESS

OWNER/DESIGNER: Bell Aerospace, Inc.

DESCRIPTION: Entrained bed process.

STATUS: This process is considered to be a third generation technology for production of low and medium Btu gas. Still in early stages of development. (1979)

THE BDM CORPORATION

5. TITLE: BRITISH GAS CORPORATION SLAGGING LURGI

OWNER/DESIGNER: British Gas Corporation

DESCRIPTION: This unit is a Lurgi gasifier that has been modified by the addition of a stirrer and the incorporation of a bottom hearth modified to discharge the ash in the form of molten slag. Sized coal flows down countercurrent to oxygen and steam. In the BGC slagging gasifier, the upper portion is essentially the same as a conventional Lurgi system. Feed of coal to the system is by means of pressurized lock hoppers. Oxidizing gases enter the bottom of the gasifier by means of a peripheral tuyere system. This system configuration employs no excess steam to moderate temperatures in the bottom hearth; hence it can tolerate a much faster throughput of oxygen and coal without coal dust entrainment in the product gas. Output of crude gas from the slagging gasifier can be as great as 8000 Btu per square foot of grate area per hour, as compared with 1750 Btu from the conventional Lurgi gasifier.

It was anticipated that the slagging gasifier would suffer from the same restriction as the Lurgi gasifier, i.e., in its current configuration, it could handle caking coals only with reduced throughput or prior mild oxidation. Most eastern U.S. bituminous coals are caking. However, Lurgi reports that caking and swelling coals have been gasified commercially in the Dorsten experimental high pressure unit, as well as by the successful test gasification of such coals as Illinois Nos. 5 and 6 and Pittsburgh No. 8 in the development unit at Westfield, Scotland. Further testing and demonstration of the slagging gasifier with caking coals may be needed to completely demonstrate satisfactory operation with such coals.

STATUS: Under the Department of Energy Demonstration Program, successful trials using highly caking run-of-mine Pittsburgh seam coal have been processed at the BGC Westfield, Scotland, 300 TPD gasifier. A design of a single modular train for a U.S. location

THE BDM CORPORATION

is contemplated if the technology is selected by DOE for a demonstration plant.

EPRI has signed a contract with BGC to operate the Westfield gasifier and auxiliaries in 1979 to evaluate its potential for use in electric power industry applications. (1979)

THE BDM CORPORATION

6. TITLE: C. E. ENTRAINED FUEL PROCESS

OWNER/DESIGNER: Combustion Engineering, Inc.

DESCRIPTION: The Combustion Engineering gasification process is based on an air-blown, atmospheric-pressure, entrained-bed gasifier. In the gasifier, a combustion chamber burns a portion of the pulverized coal and recycle char to supply the heat necessary for the endothermic gasification reaction. In the combustion section, nearly all of the ash in the system is converted to molten slag, which is then drawn off the bottom of the gasifier. The remainder of the pulverized coal is fed to the reduction portion of the gasifier where it is contacted with hot gases entering the reduction zone from the combustor. The gasification process takes place in the entrainment portion of the reactor where the coal is devolatilized and reacts with the hot gases to produce the desired product gas. The product gas, with an anticipated heating value of approximately 120 Btu/scf, leaves the gasifier at 1,700°F and enters the heat recovery train mounted on the gasifier. In this section, the hot gases pass over an evaporator and economizer to provide high-pressure steam for the steam turbine. A process steam boiler provides steam for the gasifier. The gas is further cooled by the liquid couple and leaves the heat recovery train at less than 300°F.

At this point, the gas contains solid particles and hydrogen sulfide that must be removed. Solids are removed and recycled by means of a spray drier, cyclone separators, and Venturi scrubbers. Hydrogen sulfide is removed and elemental sulphur produced by the Stretford process. The clean low-Btu gas can then be delivered to the burners of power boilers, gas turbines, or combinations of the two in a combined-cycle power generator.

The atmospheric entrained-bed gasifier offers the following advantages: all coals can be processed without pretreatment; there is no net char production; fused ash is produced which minimizes disposal problems; virtually all of the carbon in the

THE BDM CORPORATION

coal can be consumed; and all of the components except the gasifier are commercially available items with predictable operating characteristics.

It is currently processing Pittsburgh bituminous coal, and produces low-Btu gas of approximately 120 Btu/scf.

STATUS: Combustion Engineering is operating a 120 TPD pilot plant in Windsor, Connecticut. On successful completion of the pilot plant test programs the next step would be construction of a 200 MW (electric) combined-cycle demonstration plant, presently expected to be operational by 1980. (1978)

THE BDM CORPORATION

7. TITLE: COALEX

OWNER/DESIGNER: Inex Resources, Inc.

DESCRIPTION: An entrained bed slagging ash process.

STATUS: Demonstration plant under construction. (1977)

THE BDM CORPORATION

8. TITLE: COGAS

OWNER/DESIGNER: Cogas Development Company, Princeton, N.J.

DESCRIPTION: The COGAS process converts coal into both oil and gas products and to achieve this the gasification-combustion step is integrated with a multi-stage fluidized-bed coal pyrolysis step. The products of the pyrolysis step are a reactive char and pyrolysis oil and gas.

The resultant pyrolysis gas is stripped of light hydrocarbons, and processed along with the synthesis gas from the char gasification. The light hydrocarbons can be produced as a separate stream or blended back to increase the heating value of the product gas.

The char product of pyrolysis is sent to the gasifier while the product oil may be upgraded by hydrogenation to a high-grade synthetic crude oil, or by using less hydrogen in this step, to a low-sulphur fuel oil. The hydrogen for this upgrading is produced by reforming a portion of the product gas.

The product gas stream is suitable for shift conversion, purification and methanation to pipeline quality. For medium-Btu gas production, the synthesis gas is raised to a minimum pressure and cleaned to reduce sulphur and particulates. The resultant clean gas is suitable for power generation or reducing-gas process utilization such as ammonia or methanol synthesis.

STATUS: Two pilot plants are presently in operation. A 2.5 TPD plant in Princeton, N.J. utilizes an inert carrier such as a ceramic or pelletised coal ash. A 50 TPD plant in Leatherhead England utilizes an active char heat-carrier. Bechtel Associates is conducting an extensive process engineering study to oversee all the steps of the COGAS process. (1976)

THE BDM CORPORATION

9. TITLE: "COMBINED CYCLE" - BABCOCK & WILCOX

OWNER/DESIGNER: Babcock & Wilcox

DESCRIPTION: An entrained bed airfed, pressurized, water-cooled gasifier operating at 900°F under pressure, combined with a combustor to fire the gas produced at 1,600°F at 95 psi. The system drives both a high-temperature gas turbine, and a steam-turbine.

STATUS: The 480 TPD pilot plant planned by B&W and EPRI has not been initiated. Previous testing at a 60 TPD plant at the Alliance Research Center has been under evaluation since June 1961. (1979)

THE BDM CORPORATION

10. TITLE: "COMBINED-CYCLE", FOSTER & WHEELER
OWNER/DESIGNER: Foster & Wheeler, Livingston, N.J.
DESCRIPTION: A two stage entrained, slagging pressure gasifier. It is similar to the B1-GAS process developed by Bituminous Coal Research, Inc. The gasifier operates at temperatures above 2,100°F and at a pressure of 520 psi. The low BTU gas produced drives a gas and steam turbine in a combined cycle system similar to both the Babcock & Wilcox and the Westinghouse Electric Design.
STATUS: Foster-Wheeler, Empire State Electric Energy Research Corporation, and the Northern States Power Company are proposing the development of a 1,200 TPD demonstration plant to be located near Sioux Falls, South Dakota. (1979)

THE BDM CORPORATION

11. TITLE: CONSOL FIXED BED

OWNER/DESIGNER: Consolidation Coal Company (CONSOL)

DESCRIPTION: This process uses a conventional fixed bed gasifier fed with an improved feedstock of coal. The coal is processed into a mixture of coarse caking coal and non-caking pellets made by pelletizing fines in a hot pelletizing rotary kiln. The process produces a low-Btu gas with airfeed, or a synthesis gas with oxygen.

STATUS: This process has been developed to allow gasification of difficult caking coals in various reactors. It is available for applications. (1976)

THE BDM CORPORATION

12. TITLE: ELECTRIC ARC

OWNER/DESIGNER: Columbia University/Consolidated Natural Gas

DESCRIPTION: Carbon in the coal feed reacts with steam in a fluid-convection cathode (FCC), high intensity electric-arc at 800-10,000°C. The HHV of the gas product depends on reaction and subsequent quench conditions.

STATUS: Batch tests have been carried out at about 30 kW; the research and development of this process is sponsored by Consolidated Natural Gas Company. (1976)

THE BDM CORPORATION

13. TITLE: G.R.D. GASIFICATION

OWNER/DESIGNER: Garret Research and Development Compnay, La Verne, CA

DESCRIPTION: This process is the same as that described under Garrett's Coal Gasification on the high-Btu section with the absence of a shift and methanation stage.

STATUS: Same as described earlier. (1976)

THE BDM CORPORATION

14. TITLE: H.R.I. FLUIDIZED-BED

OWNER/DESIGNER: HydroCarbon Research, Inc., Princeton, N.J.

DESCRIPTION: Steam and oxygen fluidize a bed with a fuel depth of 25 feet operating at pressures up to 400 psi and temperatures from 1,450-1,650°F to produce a synthesis gas of 320 Btu/scf.

STATUS: Hydrocarbon Research, Inc., had operated a 26 inch I.D. fluidized-bed gasifier producing 3/4 million scfd of synthesis gas in the early 1960's. It is believed that H.R.I. has ceased developmental work on this process and is presently evaluating their H.R.I. Gasification Process conceived by A. M. Squires. (1976)

THE BDM CORPORATION

15. TITLE: H.R.I. GASIFICATION (SQUIRES)

OWNER/DESIGNER: Concept developed by A. M. Squires,
City College, New York.

DESCRIPTION: The gasifier incorporates a conical, fluidized-bed where high superficial velocity of the feed stream permits the bed to operate above the ash softening point of the coal (e.g., 2,200-2,300°F).

STATUS: The concept of this process was developed by A. M. Squires and examined by Hydrocarbon Research, Inc. H.R.I. has proposed the construction of a 10 TPD pilot plant and it is believed potential sponsors are sought. (1976)

THE BDM CORPORATION

16. TITLE: HYDROGEN FROM COAL FACILITY

OWNER/DESIGNER: Air Products and Chemicals, Inc.

DESCRIPTION: The production of hydrogen from coal requires the conversion of coal to synthesis gas by reaction with steam and oxygen in a commercial gasifier. Some of the resulting synthesis gas, primarily CO and H₂, is passed through a shift reactor to react the CO with steam for additional hydrogen production, followed by acid gas removal. Some of the CO is passed to a CO recovery unit. All of these process steps downstream of the gasifier involve conventional processes that are widely used in industry today, but have not been applied to a Syngas derived from coal.

In this facility, two Koppers-Totzek gasifiers, a type which has been on the commercial market for 20 to 25 years, will use dried lignite ground to fine particles. The particles are blown into the gasifiers with steam and oxygen under atmospheric pressure. Temperatures of almost 3500°F are achieved in producing the gaseous products. The product hydrogen will have a purity of 99-plus percent.

Hydrogen of at least 95 percent purity must be produced. However, depending on the industrial use selected for the hydrogen, the hydrogen may require further purification.

STATUS: DOE continuing with the construction of a demonstration near-commercial scale facility in Baytown, Texas. The plant will use 1210 TPD of coal, and produce 29.5 million SCF/day of 99 plus percent H₂ and 7 million scfd CO. By operating a near-commercial-scale plant, the DOE expects to obtain data on operation costs, the integration of major components into an operating plant, control and safety systems, and environmental characteristics of operational commercial coal gasification facilities. This data will then be made available to industry. (1978)

THE BDM CORPORATION

17. TITLE: I.C.I. MOVING BURDEN

OWNER/DESIGNER: Imperial Chemical Industries, Ltd., England

DESCRIPTION: Two separate vessels, a gasifier and a combustor are used with a steam fluidized-bed in the gasifier producing a water gas. Char is withdrawn from the gasifier and circulated to the combustor where it is partially burnt with air and recycled to the gasifier to provide the heat for the water gas reaction. This process produces a synthesis gas of approximately 300 Btu/scf without the necessity of an oxygen plant.

This process is similar to the agglomerating ash process of Union Carbide/Battelle/Chemico without the emphasis on the agglomerating characteristics of the ash.

STATUS: A large pilot plant had been constructed in England by I.C.I. to evaluate the process. However, disappointing results were obtained, primarily associated with degradation of the char which caused significant char losses from the fluidized-beds as entrained particles in the flue and product gases. (1976)

THE BDM CORPORATION

18. TITLE: I.F.E. TWO-STAGE

OWNER/DESIGNER: International Furnace Equipment Company, Ltd.

DESCRIPTION: Coal is gasified as it travels down through a fixed-bed reactor which is injected with an air-stream mixture. The ash is removed from the bottom of the reactor via a rotating grate. The off-gas produced has a heat value of 175 Btu/scf.

This producer is similar to the Marischka gasifier and to a modified (continuous air blowing) I.G.I. Two-Stage cyclic producer.

STATUS: This process had been in commercial use for many years.
(1976)

19. TITLE: I.G.I. TWO-STAGE

OWNER/DESIGNER: Il Gaz Integrate, Milan, Italy

DESCRIPTION: The two-stage gasifier consists of a lower, cyclically-operated water-gas generator upon which is superimposed a continuous vertical retort in which the coal is carbonized. Coke or char from the carbonizer gravitates to the water-gas generator and is gasified. The process follows a four minute cycle.

The blow gases (air blown) pass through the water-gas generator and up through flues built into and surrounding the superimposed carbonizing zone, and away to be burnt in the steam superheater and combustion chamber before passing through the waste-heat boiler to atmosphere. During this phase the rich gas alone from the carbonizing zone continues to flow to the gas treatment plant; the waste gas is prevented from following this path by the operation of a restricting valve on the gas main.

During the run which follows the blow, preheated steam (600-800°C) is introduced into the bottom of the generator. The resultant water gas and steam then pass up through the carbonizing charge and through a gas main carrying with them the rich gas produced in the carbonizing zone. Most of the heat required for carbonization is supplied by the water gas and the remainder by the waste gases as described above. The off-gas is approximately 335 Btu/scf and though the process is air-blown, little nitrogen appears in the product gas.

STATUS: There were many examples of this kind of process. The process was originally developed by Italy's Il Gaz Integrale in the 1940's. Other plants of this type which are similar in design are the "Tulley" and "Power-Gas" complete gasification plants. Two stage processes in which the rich gas from the first stage was taken off separately and recycled in order to decompose the hydrocarbons were developed for synthesis gas manufacture.

THE BDM CORPORATION

Examples of these are:

Pintsch Hillebrand Process

Koppers Recycling Process

Viag Synthesis-Gas Progress

Bubiag Didier Process. (1976)

THE BDM CORPORATION

20. TITLE: KELLOGG FIXED BED

OWNER/DESIGNER: M. W. Kellogg Co., Piscataway, N.J.

DESCRIPTION: This process employs a low-pressure (30-50 psi) fixed-bed, revolving-grate gasifier to produce a low Btu fuel gas (150 Btu/scf) with air, and a medium-Btu fuel gas (300 Btu/scf) with oxygen. By-product tar and oil are used as plant fuel or chemical feedstock.

STATUS: The Company was studying the formation of a Consortium to erect a demonstration plant at an, as yet, unselected utility site. (1976)

THE BDM CORPORATION

21. TITLE: KELLOGG MOLTEN SALT

OWNER/DESIGNER: M. W. Kellogg, Company, Houston, Texas

DESCRIPTION: This process is the same as the high-Btu "Molten-Salt" process described earlier. Using air instead of oxygen, however, yields a lower Btu gas of approximately 150 Btu/scf.

STATUS: The company has ordered the formation of a consortium to erect a demonstration plant at an as yet, unselected utility site. (1976)

THE BDM CORPORATION

22. TITLE: KERPELY PRODUCER

OWNER/DESIGNER: U.S. Bureau of Mines

DESCRIPTION: Coal passes through a lock hopper down into a fixed-bed cylindrical unit where it is gasified by a steam-oxygen (or air) blast through a revolving grate which removes the ash continuously. The unit operates at atmospheric pressure to produce a 260 Btu/scf gas with oxygen or a 130 Btu/scf gas with air.

STATUS: A 7 foot internal diameter unit was operated by the U.S. Bureau of Mines research station at Louisiana, Missouri, producing about 2 million scfd of 260 Btu/scf synthesis gas with oxygen blasts. (1976)

THE BDM CORPORATION

23. TITLE: KOPPERS-TOTZEK (K-T)

OWNER/DESIGNER: Heinrich Koppers GimbH

DESCRIPTION: The gasifier is a refractory-lined, cylindrical vessel with conical ends. Oxygen, steam and coal react at about atmospheric pressure and 3,300°F. Fixed carbon and volatile matter are gasified to produce off-gas containing carbon monoxide and hydrogen. Coal ash is converted into molten slag a proportion of which drops into a water-quench tank, the remainder is carried by the gas. Gas leaving the gasifier is quenched with water to solidify entrained molten ash. After passing through a waste-heat boiler, the gas is scrubbed to remove sulphide and a controlled quantity of carbon dioxide is removed by purification. The purified gas may then be shifted and methanated, dehydrated and purified to remove carbon dioxide, thus producing SNG, or used "as is" for synthesis gas or as a fuel. Dry, pulverised coal of any type may be used as in other entrained-flow gasifiers. These gasifiers are limited to atmospheric pressure operation, at present, although operation at elevated pressures is being considered.

STATUS: Since 1952, this process has been in operation commercially. There are 16 Koppers-Totzek plants operating around the world none of which are in the U.S.A. At the present time, one of the more recent K-T installations is a 6-unit gasification facility to produce 95 million scfd of hydrogen for an ammonia plant for AE&CI in South Africa. (1978)

THE BDM CORPORATION

24. TITLE: LASER IRRADIATION PYROLYSIS

DESCRIPTION: In the Laser irradiation of coal, pyrolysis proceeds rapidly at high temperatures to produce a gas containing acetylene, hydrogen, carbon monoxide and carbon dioxide. No liquid product or significant amounts of methane are produced, due to the high temperatures generated by Laser energy. The gas yield varies inversely with coal rank.

STATUS: Experiments have been conducted by the U.S. Bureau of Mines to investigate Laser pyrolysis of coals of various ranks. The gaseous products of pyrolysis were analyzed by mass spectrometry. (1976)

THE BDM CORPORATION

25. TITLE: LURGI

OWNER/DESIGNER: Lurgi Khole Und Mineral Oeltechnik

DESCRIPTION: The Lurgi gasifier has a fixed-bed with lockhopper feed and dry-ash lockhopper discharge. It can be operated either air-blown or oxygen-blown; for SNG production, however, oxygen must be used. Most Lurgi plants use non-caking sub-bituminous coal or lignite. The coal fed to existing Lurgi generators must be carefully sized, typically 0.25 to 1.5 inches. The fines screened out of the Lurgi gasifier feedstock are usually diverted to an adjacent steam boiler plant.

Lurgi generators have accepted some caking coals but with reduced throughput. Another method of handling this problem is to oxidize the caking coal midly prior to input as practiced in the HYGAS system. This step will generally work with any gasifier which has difficulty with caking coal.

Commercial Lurgi gasifiers are currently about 12 feet in diameter; therefore, large plants have several generators in parallel. For example, the SASOL II plant in South Africa will have 34 Lurgi gasifiers with a combined capacity of 1,100 million scfd of purified synthesis gas.

The currently available lockhoppers for feeding coal to and discharging ash from a Lurgi gasifier limit its operating pressure to a maximum of about 540 psi. This is not a serious handicap in producing SNG, because it can be compressed to U.S. pipeline pressure of 1,000 to 1,100 psig. A 1,400 psi, 240 TPD experimental unit is under construction at Dorsten, Federal Republic of Germany. For comparison, throughput to a standard 12-foot diameter Lurgi gasifier is about 800 tons of coal per day.

STATUS: Lurgi gasifiers are operating in Korea, Federal Republic of Germany, South Africa, Great Britain, India, Pakistan, Australia, and Czechoslovakia. The SASOL plant in South Africa is the largest; it produces synthesis gas, mainly for conversion

THE BDM CORPORATION

to automobile gasoline. A second plant, SASOL II, is expected to be ready for commissioning in late 1979 or early 1980. While not intended to produce SNG, the plants, in combination, would be able to produce enough synthesis gas to make 340 million scfd of high-Btu substitute natural gas through further methanation. The largest SNG plant now contemplated in the United States would produce about 250 million scfd.

Chemotechnik & Steag carried out studies of combined gas/steam cycle power generation at a 170 MW unit built in a linear power station, comprising a 74 MW gas turbine combined with a 96 MW steam turbine, utilizing a modified Lurgi gasifier for power in Lunen, Germany. Recently, expansion of the plant to 800 MW was announced.

In the U.S., Commonwealth Edison and EPRI announced in early 1974 construction of a \$19 million low-Btu gasification unit at the Powerton Generating Station near Pekin, Illinois. The plant is scheduled for operation in 1977 converting 480 TPD of coal into clean fuel for a 20 MW gas turbine. The installation will utilize two Lurgi gasifiers.

The U.S. Bureau of Mines is also conducting studies on the first Lurgi pressure-coal gasifier installed in the U.S. by Blaw-Knox at the Pittsburgh, Pa., center and has a pilot-scale Lurgi slagging gasifier at Grand Forks, N.D., for operation on lignite.

In the United Kingdom, both the British Gas Council and the B.C.U.R.A. have conducted pilot-scale tests on Lurgi slagging gasifiers, blown with a steam-oxygen mixture, to produce a mid-Btu synthesis gas. (1978)

THE BDM CORPORATION

26. TITLE: MARISCHKA

DESCRIPTION: In commercial operation for many years, the Marischka coal gasifier has been used mainly for the gasification of anthracite or coke. It produces on the order of 2.5 to 3.5 million scfd of gas.

The gasifier features an annular boiler with upper and lower sections connected by closely spaced connective rows of water tubes within the reactor. The hot gases leaving the gasifier pass into a chamber external to the lower steam jacket and leave near the base of the vessel. It is pressurized at approximately 100 psi.

STATUS: No information available. (1976)

THE BDM CORPORATION

27. TITLE: MOUNTAIN FUEL ASSOCIATES ENTRAINED PROCESS

OWNER/DESIGNER: Mountain Fuel Associates

DESCRIPTION: Entrained bed Process

STATUS: This process is considered to be in the early stages of development. It is part of the third generation of technology for low and medium Btu gas production. (1979)

THE BDM CORPORATION

28. TITLE: MULTIPLE FLUIDIZED-BED

OWNER/DESIGNER: Bituminous Coal Research Inc.

DESCRIPTION: Multiple fluidized-beds are employed in a gasifier to produce a gas free of liquids. Air is used to produce a low Btu off-gas of 160 Btu/scf. This process is similar to the high-Btu BI-GAS process.

STATUS: Blaw-Knox Division (Dravo Corporation) was awarded a contract for the engineering, procurement, and construction of a 100 PPH process engineering development unit (PEDU) to be constructed at Monroeville, Pa. Construction commenced in 1974, the work being sponsored under an O.C.R. contract of \$2.75 million for research and development of the suitability of the process for the production of low-Btu fuel gas. (1976)

THE BDM CORPORATION

29. TITLE: OTTO RUMMEL SLAG BATH (DOUBLE SHAFT)

OWNER/DESIGNER: Dr. C. Otto and Company

DESCRIPTION: This process is analogous to the Kellogg molten-salt process, except that sodium carbonate is used to remove the ash from the slag bath.

An exothermic air-blast and the endothermic water gas phase are applied to separate sections of a common slag bath produced by means of a vertical partition reaching a short distance into the bath. Thus, a relatively nitrogen-free synthesis gas can be generated using air to produce a gas of 270 Btu/scf. Excess slag is continuously withdrawn via an overflow weir located in a central annulus.

STATUS: Due to discouraging results of tests conducted in a pilot plant constructed in 1962 in London by the Gas Council Research Station, this design has been rejected. (1976)

THE BDM CORPORATION

30. TITLE: PANINDCO

DESCRIPTION: Pulverised coal (-200 mesh) is fed to the center of a refractory-lined cylinder with a domed top. Oxygen-steam or air-steam mixtures are fed into an annular space surrounding the coal feed. Steam is fed through several nozzles where it is used as a gasifying medium and to moderate reaction temperatures and protect the refractory lining. Ash and product gas are removed from the bottom of the vessel. With oxygen a synthesis gas of 210 Btu/scf and with air a gas of 125 Btu/scf is produced.

STATUS: The process has been tested on a pilot scale in an experimental plant processing 1,600 PPH of coal feed in Rouen, France, installed in 1950.

THE BDM CORPORATION

31. TITLE: PINTSCH HILLEBRAND

OWNER/DESIGNER:

DESCRIPTION: The process involves primary distillation and gasification in a lower chamber. Distillation gas is recycled to a producer gas generator and regenerative heaters for gas and steam heating. These supply heat and steam to the gasification chamber where water gas with a heating value of 280 Btu/scf is produced.

STATUS: This process has been in commercial use for many years in Germany. (1979)

THE BDM CORPORATION

32. TITLE: PHILADELPHIA AND READING

OWNER/DESIGNER: The Philadelphia and Reading Corporation

DESCRIPTION: No details of the process are available. The Philadelphia and Reading Corporation retained the Blaw-Knox Chemical Plants Division of the Dravo Corporation to provide designs and definitive cost estimates for the production of 100 million scfd of 98% pure hydrogen from anthracite culm (refuse screenings), and silt. The hydrogen obtained could be used in the production of urea, methanol, formaldehyde, pipeline gas, ammonia, nitric acid, and ammonium nitrate.

STATUS: Nothing has been done beyond the initial study. (1976)

THE BDM CORPORATION

33. TITLE: POWER-GAS
OWNER/DESIGNER: Power-Gas Company
DESCRIPTION: Coal fed to the top of the unit is gasified with air at atmospheric pressure to yield a 160 Btu/scf off-gas with continuous ash removal from the base of the vessel.
STATUS: This process has been in commercial operation for many years. (1979)

THE BDM CORPORATION

34. TITLE: POWERTON COMBINED CYCLE AND TEST FACILITY

OWNER/DESIGNER: Fluor Corporation (Irvine, California), designer

DESCRIPTION: This DOE sponsored the coal gasification combined-cycle test facility will produce a low Btu gas of 100-130 Btu/SCF to fuel a gas turbine-generator system exhausting to a heat recovery steam generator. The initial gasification facility will consist of two Lurgi gasifiers. One gasifier will serve as a spare, since one operating gasifier will satisfy the capacity of the gas turbine planned for the facility. It is planned to operate both gasifiers at various capacities.

Crude gas from the gasifiers will be cleaned of tars and oils in a quench scrubber, cooled, scrubbed for removal of hydrogen sulfide, and saturated with water before passing to the gas turbine test facility. Sulfur removal will be by hot potassium carbonate scrubbing. The acid gas from this system will be scrubbed to remove ammonia, and converted to elemental sulfur in the sulfur recovery unit. Tar and oily condensates will be collected and gravity-separated in the tar-oil separation unit. Tar will be recycled to the gasifier.

A General Electric Frame Five gas turbine with an output capability of about 20 MW, is being modified for testing in the first phase of the program.

In addition to providing data for integration and control methodology of a gasifier with a combined cycle power generation system, the Powerton Plant will serve as a unique and flexible test facility. It will be possible to evaluate quickly and efficiently new coal gasification systems as well as advanced turbines, fuel cells and other conversion devices being developed by programs within the Department of Energy. The key features of this facility are the provisions of allotted space for these advanced systems at the site; the in-place coal handling facilities which represent a major cost item; the in-place equipment for handling waste and effluents; and the ability to accept

THE BDM CORPORATION

full-scale plant product output from a gasification system. The latter provision is an exceptional feature since the existence of a 1700 MW power plant at the site permits the use of the product gas as fuel for its conversion to electricity, and actually receive income for usable fuel or power generated. This will drastically reduce both cost and time required to bring new ideas to commercialization.

STATUS: DOE planning construction of this test facility scheduled for start-up by 1981. It will have a feed rate of 20 TPH of coal. (1978)

THE BDM CORPORATION

35. TITLE: RAPID, HIGH TEMPERATURE

OWNER/DESIGNER: Eyring Research Institute

DESCRIPTION: A rapid, high temperature process to convert coal to a clean fuel gas.

STATUS: A research contract for \$208,000 was awarded for research by the Office of Coal Research. (1976)

THE BDM CORPORATION

36. TITLE: RILEY-MORGAN

OWNER/DESIGNER: Riley Company

DESCRIPTION: This low pressure coal gasifier utilizes a fixed-bed system. The product gas HHV varies with the use of air (low) or oxygen (medium), and can be utilized to produce industrial fuel gas. These single-stage gasifiers can accept moderately caking coal; with a mechanical agitator, more strongly caking coals can be used.

STATUS: Updated versions are offered with Morgan Construction Company gasifiers.

THE BDM CORPORATION

37. TITLE: ROCKET DYNE CORPORATION'S ENTRAINED PROCESS

OWNER/DESIGNER: Rocketdyne Corporation

DESCRIPTION: An entrained bed process

STATUS: This process is considered to be a third generation of technology for production of low and medium Btu gas. It is still in early stages of development. (1979)

THE BDM CORPORATION

38. TITLE: ROCK GAS

OWNER/DESIGNERS: Atomics International Division of Rockwell
International Corporation

DESCRIPTION: Coal and sodium carbonate are transported by compressed air (10-20 atm) into the bottom of the melt bed in the molten salt furnace. The molten pool is composed of sodium carbonate along with sodium sulfide, and sodium sulphate formed during the process. Gasification reactions (partial oxidation and pyrolysis) take place at 1,800°F and 20 atm. Conducting gasification reactions in the molten salt medium permits very high oxidation rates and results in trapping ash and sulphur in the melt. Process economics favor operation of the gasifier at elevated pressure with recovery of energy from the product gas. The fuel gas produced has a heating value of approximately 150 Btu/scf and is predominately carbon monoxide, hydrogen, and nitrogen. Because the melt retains the ash and sulphur from the coals, the melt must be continuously withdrawn from the furnace so that fresh sodium carbonate can be added. The melt stream is subsequently regenerated by an aqueous process in which the melt is quenched and mixed with water to dissolve the salt.

The hot fuel gas from the molten salt furnace may be combusted in a gas turbine which converts the energy of the fuel gas to electric energy. After passing through the turbine, the exhaust gas may be used to produce steam for operating a steam turbine, thereby producing additional electricity. Flue gas (primarily carbon dioxide and nitrogen) leaving the boiler heats incoming combustion air and is then used for sodium carbonate regeneration.

STATUS: A 24 ton per day process development unit is under construction. (1978)

THE BDM CORPORATION

39. TITLE: RUHRGAS VORTEXR

OWNER/DESIGNER: Ruhrgas A. G.

DESCRIPTION: Finely-crushed high-ash coal or lignite is introduced with air preheated to 1,300°F into a vortex chamber for gasification under slagging conditions and without steam. The reactants pass upward into a larger diameter shaft where most of the gasification occurs at 3,100°F while the slag is removed at the bottom. The off-gas is passed into cyclones then bag filters for dust removal and the recycling of entrained char. The product is 100-120 Btu/scf fuel gas.

STATUS: This commercial process, available for many years, has been supplanted by more modern technology with improved operating characteristics. (1979)

THE BDM CORPORATION

40. TITLE: RUMMEL SLAG BATH

OWNER/DESIGNER: Union Reinische Braunkohlen Kraft Stoff A. G.

DESCRIPTION: Suspended fuel particles and gasifying medium are injected through nozzles into a slag bath maintained in the base of the reactor. Coal particles are entrained in the slag where they are brought into intimate contact with the other reactants for a high conversions of coal to gas and of ash to slag. Off-gases are cooled in the top of the reaction and the continuously overflowing slag is quenched in water. Operated with air or oxygen, the process can produce a 110 Btu/scf fuel gas or a 270 Btu/scf synthesis gas.

STATUS: The process has been commercially available for many years. (1979)

THE BDM CORPORATION

41. TITLE: SAARBERG-OTTO PROCESS

OWNER/DESIGNER: Saarberg-Otto

DESCRIPTION: The Saarberg/Otto gasifier is a high-temperature, entrained flow, slag bath gasifier. The principle is based on the Otto Rummel slag bath gasifier. It is characterized by a rotating molten slag bath, turned through the injection of feed-stock and O_2 . With O_2 it produces a synthesis gas suitable for production of ammonia and methanol, and with air it produces a low-Btu gas.

STATUS: A 132 TPD demonstration plant is under construction at Volkslingen Furstenhausen, but presently no plants of this nature are actually in operation.

THE BDM CORPORATION

42. TITLE: SHELL-KOPPERS

OWNER/DESIGNER: Shell International Research Company-Koppers Company

DESCRIPTION: The Shell-Koppers process uses a one-stage entrained-flow gasifier which has not yet reached commercial status. The process is a merger of technologies from Shell's well-known oil gasification process and from the Koppers-Totzek coal gasification process. This latter process is limited to atmospheric pressure, but the new Shell-Koppers process will operate at about 450 psi. Coal feed will be by a high pressure slurry of coal and water; ash will be discharged as molten slag. The process will consume oxygen, but there has been no indication of the quantity.

STATUS: A 10 TPD pilot plant is in operation in Amsterdam, Holland at Shell's research center. A 150 TPD plant is in start-up at Shell's Hamburg, Germany refinery. Support for the plant has been solely by Shell. (1979)

THE BDM CORPORATION

43. TITLE: STIRRED FIXED-BED ("MORGAS") PROCESS

DESCRIPTION: The fixed bed gasifier is equipped with a stirrer to break up any coke that is formed in the upper section. The stirrer moves vertically in the reactor as well as rotating on its shaft. Coal is fed to the top of the gasifier while steam and air are introduced at the base of the bed through a revolving grate. Ash removal to the ash pit from the gasifier is accomplished by the revolving grate. Production of SNG by adding shift and methanation steps, as in the SYNTHANE process, is possible. Gasification of highly-coking coals is possible by using the stirrer to agitate the bed.

STATUS: An 18 TPD pilot plant is in operation at the Bureau of Mines, Morgantown, W.Va. A design contract has been let to McDowell-Willman Engineering to design a reactor for this process. A three-year research and development program on a system that will provide a hot, clean working fluid from this process suitable for magnetohydrodynamic power generation. (1976)

THE BDM CORPORATION

44. TITLE: STOIC TWO-STAGE GASIFIER

OWNER/DESIGNER: Stoic Construction Ltd., Johannesburg, South Africa

DESCRIPTION: Two stage gasifiers have the inherent advantage of generating by-product coal tar in semi-distilled form rather than as the more noxious types of pitch or soot. Two-stage gasifiers are in commercial service in South Africa, Europe, Australia, and Japan, but have only recently been offered in the U.S. The gasifier uses low-sulfur non-caking coals, air, and steam. Tar contained in the top gas can be removed by electrostatic precipitator. This tar has properties similar to No. 6 fuel oil. It produces low Btu gas of app. 160 Btu/scf. The process has a thermal efficiency of app. 80%.

STATUS: A SOTIC gasifier was under construction for the University of Minnesota as part of the "Gasifiers in Industry" Program of DOE. It is a 10 foot diameter gasifier designed for producing low-Btu gas for fuel to boilers presently using oil and natural gas. Foster-Wheeler Energy Corporation is of Livingston, N.J. the licensed vendor of the process in the U.S. The University of Minnesota demonstration project will have a plant capacity of 3 TPD of coal. (1978)

THE BDM CORPORATION

45. TITLE: SUBMERGED COAL COMBUSTION

OWNER/DESIGNER: Applied Technology Corporation

DESCRIPTION: The process, essentially similar to ATGAS/PATGAS, is based on the molten-iron gasification process using an air/coal feed to produce a 185 Btu/scf off-gas. The ATGAS/PATGAS processes, on the other hand, are oxygen/coal based, using the same molten-iron coal gasification process.

STATUS: Bench scale, short duration tests have been conducted. The U.S. Environmental Protection Agency is sponsoring a design study of a 50-100 MW power generating plant to use the low-Btu off-gas product. (1976)

THE BDM CORPORATION

46. TITLE: SYNTHANE

OWNER/DESIGNER: U.S. Bureau of Mines

DESCRIPTION: The Synthane reactor is a 600 - 1000 psi single-stage fluidized-bed preceded by a fluidized-bed pretreater operating at the same high pressure. Coal feed to the pretreater is through lockhoppers. The discharge of dry ash-rich char from the primary gasifier is also through lockhoppers. Synthane uses oxygen, and the process is tailored to the production of pipeline SNG because of its high Btu value using oxygen (355 Btu/scf and 28,000 scf/ton coal). Within air, the gas has a Btu content of 165 Btu/scf.

Decaked coal from the pretreater enters the gasifier at the top and a mixture of steam and oxygen is introduced at the bottom to fluidize the bed. The gasifier operates at pressures up to 1,000 psi and at a fluidized-bed temperature of 1,800°F. Product gas (synthesis gas) leaves overhead and unconverted coal or char, is withdrawn at the bottom. The char can be burned to generate all the steam required in the process. After removal of tars and solids, the gas passes through a shift converter and acid-gas removal system. Finally, the product gas goes to the methanator, increasing the heating value to that of natural gas.

STATUS: The Synthane process was developed by the U.S. Bureau of Mines, a DOE predecessor agency. The Pittsburgh Energy Technology Center completed construction of a 72 TPD pilot plant at Burcetown, Pennsylvania, 1976. A 98-hour continuous run was reported at the Ninth AGA Pipeline Gas Symposium. Under the actual conditions of the pilot study, using the Montana Rosebud Coal the off gas produced contained 252 Btu/scf, with oxygen feed. (1978)

THE BDM CORPORATION

47. TITLE: TEXACO GASIFICATION

OWNER/DESIGNER: Texaco

DESCRIPTION: The Texaco coal gasification process is derived from Texaco's partial oxidation process for generating synthesis gas from naphtha, residual oil, or other petroleum liquids. The Texaco reactor is a high-pressure (350 - 2500 psi) downflow entrained bed reactor using oxygen. Coal feed is pumped in as an aqueous slurry; the ash is discharged as molten slag.

STATUS: Ruhrkohle and Ruhrchemie began startup of a 10 million scfd synthesis gas plant using the Texaco process in West Germany early in 1978. Texaco Development Company operates a 15-TPD pilot plant at Montebello, California. Extensive background on a variety of US coals is available. Three 150-TPD plants have been licensed using Texaco coal gasification and include:

<u>COMPANY</u>	<u>LOCATION</u>	<u>APPLICATION</u>
Ruhrchemie	Essen, Germany	Petrochemicals
TVA	Muscle Shoals, AL	Ammonia
Dow Chemical Co.	Plaquemine, LA	Power

Currently a project based on Texaco technology that would utilize fuel gas to generate electricity in gas turbine-steam turbine equipment (combined cycle) is planned by Southern California Edison Company. The plant would handle 1,000 TPD of coal. Funds for the detailed design of the plant are being provided by Southern California Edison, Texaco Oil Company, and EPRI. The first demonstration plant should come on line in late 1983, and commercial plants could be on line by the late 1980s. The DOE supports design of a 1,700 TPD plant for the W. R. Gace Company. (1979)

THE BDM CORPORATION

48. TITLE: THYSSEN GALOCSY

OWNER/DESIGNER:

DESCRIPTION: A cylindrical fixed-bed gasifier is fed coal at three levels. Recycle gas, steam, and oxygen are also added in the base section while oxygen is fed at the upper two levels. The process is operated at temperatures above the fusion point and at atmospheric pressures to yield a synthesis gas of approximately 320 Btu/scf.

STATUS: Commercial scale generators producing approximately 30 million scfd have been built. (1976)

THE BDM CORPORATION

49. TITLE: TWO-STEP COAL PYROLYSIS-GASIFICATION PROCESS

OWNER/DESIGNER: West Virginia University, Department of Chemical Engineering

DESCRIPTION: A sand fluidized-bed for pyrolysis accepts coal, including coking coal, at 1,400°F. Product char is separated from the effluent gas and reacted in a gasifier to produce fluidizing gases for the pyrolyzes. A small amount of raw coal is added with the char to the gasifier to maintain the operating temperature of the gasifier at 1,900°F and to obtain sufficient gas to fluidize the coal entering the pyrolyzes.

STATUS: The fluidized bed reactor has been demonstrated in bench-scale experiments. The gasification step would employ conventional steam-air gasification. A conceptual study has been made for application of the process to power generation by coupling the TWO-STEP process with an advanced-design combined steam and gas turbine power cycle. The conceptual design is estimated to be more efficient than a single-step coal gasifier system. (1976)

THE BDM CORPORATION

50. TITLE: TRW ENTRAINER PROCESS

OWNER/DESIGNER: TRW

DESCRIPTION: An entrained bed process

STATUS: This process is considered to be a third generation technology for production of low and medium Btu gas. Still in early stages of development. (1979)

THE BDM CORPORATION

51. TITLE: U-GAS

OWNER/DESIGNER: The Institute of Gas Technology

DESCRIPTION: A fluidized bed gasifier operating at 350 psi and 1,900°F is fed from an intermediate chamber operating at 350 psi and 800°F using crushed coal that requires retreating if of the caking variety. Air and steam are admitted to the base of the gasifiers; ash removal is via an intermediate chamber, also at the base. The gases are passed from the gasifier and preheater through heat recovery and sulfur removal systems, then to power recovery turbines to reduce the pressure to desired levels. Oxygen produces a medium Btu fuel gas; substitution of air leads to a gas with 155 Btu/scf.

STATUS: The U-GAS process has been under serious consideration as the first stage of the HYGAS demonstration plant design in part because of the attractiveness of the ash removal feature. (1978)

THE BDM CORPORATION

52. TITLE: U.G.I. BLUE WATER GAS

OWNER/DESIGNER: U.G.I. Corporation

DESCRIPTION: A reactor containing a bed of coke is steam-blasted producing gasses which are passed off and collected. Air is then blown through the bed to restore the temperature of the bed to the level at which it stood before the water-gas reaction. This phase produces a nitrogen rich gas which is held separately from the first phase synthetic gas. The gas produced is approximately 295 Btu/scf.

STATUS: This process has been in commercial use for many years. The process has been modified for continuous operation with steam and oxygen for production of 270 Btu/scf synthesis gas by E.I. Du Pont de Nemours Company in a commercial plant.

Other processes similar to this modified Blue Water Gas producer are the Thyssen Galoczy Synthesis Gas process, the Leuna Synthesis Gas process and the Kerpely Synthesis Gas process, all of which produce a 250 Btu/scf synthesis gas by using steam and oxygen blasts over coke beds. (1976)

THE BDM CORPORATION

53. TITLE: UNION CARBIDE AGGLOMERATING ASH FOR LOW-MEDIUM BTU GAS

OWNER/DESIGNER: Union Carbide Corporation, Battelle Memorial
Institute, Columbus Laboratories

DESCRIPTION: This is the same process described earlier for the production of high-Btu gas. Without methanation this process is suitable for production of low-medium Btu gas, and combined cycle application for the generation of electricity. The self-agglomerating process produces a flue gas sufficiently clean for use directly through gas turbines for power generation. There is also no need for an oxygen plant to produce nitrogen free gas because of its use of recirculated hot ash pellets from the combustion bed.

STATUS: It was believed that the greatest near-term potential for this process was combined cycle power generation from mid-Btu gas with a high efficiency estimated at (42-44%). Combined cycle plants are operational in France and Germany. Operational plants are expected in the U.S. in the 1980's.

Union Carbide and the Montana Power Company applied in December of 1973 for funding of a mid-Btu gasification plant with a coal feed of 2,000 TPD. (1976)

THE BDM CORPORATION

54. TITLE: WASHINGTON FUEL CELL

OWNER/DESIGNER: Westinghouse Electric Corp., Research and
Development Center, Pittsburgh, PA

DESCRIPTION: Coal is fed to a gasifier operating at about 1,800°F to produce gas which energizes solid-electrolyte fuel cells immersed in the gasifier bed. Water vapor and carbon dioxide from the fuel cells react with the coal during gasification.

STATUS: This concept was studied by Westinghouse from 1962 to 1970 under an O.C.R. -- sponsored R&D program known as "Project Fuel Cell." Jackson and Moreland Division of United Engineers and Constructors, Inc. provided review and evaluation reports on the project under an O.C.R. contract.

The concept was found to be attractive, however, no project is now current. (1976)

55. TITLE: WELLMAN-GALUSHA

OWNER/DESIGNER: McDowell-Wellman and Wellman-Galusha

DESCRIPTION: Crushed coal (3/16" x 5/16") dried and fed by an oxygen-steam or air steam mixture, is introduced through a revolving grate at the bottom. Gasifiers are available with or without an agitator. The agitator producer has a slowly revolving horizontal arm which spirals vertically below the surface of the fuel bed. The temperature of the gas leaving the gasifier is in the range of 1,000 to 1,200°F., depending on coal type. Pressure is near atmospheric. Ash is removed continuously through a slowly revolving eccentric grate at the bottom of the reactor.

Raw gas is passed through a waste-heat recovery section. Ash, carried over by gas, and tar are removed by scrubbing. The gas is then compressed and shifted. Pipeline-quality gas may be produced by purification, methanation and dehydration (O₂ feed).

The yield of gas per ton of coal or coke gasified varies with the moisture and ash contents of the fuels fired. Under good operating conditions with bituminous coals of weakly-caking types a yield of 60,000 to 150,000 scf/ton of 168 Btu/scf gas can be considered typical. Wellman gasifiers vary from eight feet to eleven feet in internal diameter, the largest size having a capacity of 84 TPD of coal with a gas output of about eight million scfd. Because of the small size of the reactors, the vendors can only offer units suitable for single, large industrial plants or a complex of smaller plants, requiring fuel or synthesis gas. Higher capacities can be achieved using oxygen.

STATUS: This process has been commercially available for over 30 years. The plants produce either a fuel gas (with air) or a synthesis gas (with oxygen). Wellman Incandescent Ltd. is offering a modified two-stage producer-gas process, similar to the Wellman mechanical gas producer, which produces a hot, detarred fuel gas. Twenty two-stage producers are in operation

THE BDM CORPORATION

or on order. A Wellman-Galusha single-stage gasifier has been installed at the Glen-Gery brick plant at York, Pennsylvania as part of the "Gasifiers In Industry" DOE program. One ton of anthracite coal per hour will be converted in the burner. Water and air are introduced in the gasifier. The gas stream is then purified by cyclones which remove dust. The low-Btu gas produced is being used to fire a brick kiln. (1978)

NOTE: In North and South America, Wellman gasifiers are offered by Applied Incandescent Ltd. of London. (1976)

THE BDM CORPORATION

56. TITLE: WELLMAN-INCANDESCENT TWO-STAGE GASIFIER

OWNER/DESIGNER: Applied Technology Corp., Houston, Texas (owns U.S. process license)

DESCRIPTION: The bulk of the gasification in the Wellman-Incandescent moving-bed two-stage gasifier takes place in the lower stage just above a rotating grate. This stage is fed with char from the upper stage and with air and steam. A boiler for steam at 25 psi is attached to a jacket on the gasifier. The 950° to 1100°F gas created in the lower stage is allowed to exit in two separate streams. One stream exits after heating the upper stage by indirect exchange. The other stream leaves at 200° to 300°F after heating the upper stage by direct contact. Hence, the upper stage achieves the "distillation" of the feed coal. Because of its low temperature, the tars driven off are not asphaltic and are able to be effectively collected in a tar cyclone. Tar droplets that by-pass this cyclone are evaporated by mixing this upper stage gas with a portion of the hot lower stage gas. The remainder of the hot, tar-free lower stage is cooled at 400°F and completely cleaned (filtered) for use as fuel in the spray drying of milk products by direct contact. This process produces low Btu gas of app. 170 Btu/scf. The planned U.S. demonstration uses subbituminous coal. It has a projected thermal efficiency of 88%.

STATUS: Land O'Lakes creamery in Perham, Minnesota, is constructing a Wellman-Incandescent gasifier as part of the "Gasifiers in Industry" program of DOE to demonstrate the use of this technology to produce a low-Btu fuel for replacement of natural gas in boilers, and space heaters, and in the drying of milk producers directly. It is scheduled for a 1980 start-up. (1978)

THE BDM CORPORATION

57. TITLE: WESTINGHOUSE LOW-BTU PROCESS (FLUIDIZED BED)

OWNER/DESIGNER: Westinghouse Electric Corporation, Research and Development Center, Pittsburgh, PA

DESCRIPTION: Crushed (1/4" x 0), dried coal is fed into a central draft tube of the devolatilizer-desulphurizer unit (gasifier). Coal and internally-recycled solids are carried upward in the draft tube by hot gases from a combustor flowing at a velocity greater than 15 fps. Recycle solids flow downward in a fluidized bed surrounding the draft tube at rates up to 100 times the coal feed rate. The coal feed is diluted to prevent agglomeration as it devolatizes. Heat requirements of the coal-system gasification reactions are provided by hot gases produced in the combustor. A lime sorbent is added to the devolatilizer-desulphurizer reactor to remove sulphur which is present as hydrogen sulphide in the gas. Spent sorbent is withdrawn from the reactor after stripping out the char. Spent sorbent is regenerated and recycled to the reactor. Char is withdrawn from the top section of the devolatilizer-desulphurizer and fed to the combustor. Char is gasified with air and steam at the desulphurizer and fed to the combustor. Char is gasified with air and steam at 2,100°F. Ash agglomerates at the temperature of the combustor and is removed. Raw product gas (135 Btu/scf) from the devolatilizer-desulphurizer unit passes through a cyclone to remove fines and then through a heat-recovery unit. Fines are recycled to the combustor.

STATUS: This process is being tested in a 1,200 lb./hour pilot plant at Waltz Mill, PA. Westinghouse in late 1972 began a nine-year research and development program, expected to cost U.S. \$80 million, co-sponsored by Bechtel Corp., AMAX Coal, Peabody Coal Co. and the Public Service of Indiana. Eleven electric power utilities* are also sponsoring the program as associate members. A 60 ton per hour commercial, low-Btu gasification and electric power plant is under construction at the Dresser Station

THE BDM CORPORATION

of the Public Service of Indiana at Terre Haute, Indiana. This project, will utilize a combined-cycle coal gasification-power generation system fueled by the Westinghouse gasifier. The plant was scheduled to begin operation in 1978.

- * Northern Indiana Public Service Company
- Tennessee Valley Authority
- Consumers Power Company
- Union Electric Company
- Duke Power Company
- New England Electric System
- Columbus and Southern Ohio Electric Company
- Pennsylvania Power and Light Company
- The Montana Power Company
- Tampa Electric Company
- Iowa Power and Light Company (1979)

58. TITLE: WINKLER

OWNER/DESIGNER: Davy Powergas, Inc., Lakeland, Florida

DESCRIPTION: Crushed coal is dried and fed to a fluidized-bed gasifier through a variable-speed screw feeder. Coal reacts with oxygen and steam to produce off-gas rich in carbon monoxide and hydrogen of approximately 290 Btu (120 Btu/scf if air is used). Because of the high temperatures (1,500-1,800°F), all tars and heavy hydrocarbons are reacted. About 70% of the ash is carried over by the gas and 30% is removed from the bottom of the gasifier by the ash screw. Unreacted carbon carried over by gas is converted by secondary steam and oxygen in the space above the fluidized-bed. As a result, maximum temperature occurs above the fluidized-bed. To prevent ash particles from melting and forming deposits in the exit duct, gas is cooled by a radiant boiler section before it leaves the gasifier. Raw gas leaving the gasifier is passed through a further waste-heat recovery section. Fly-ash is removed by cyclones, wet scrubbers and an electrostatic precipitator. This gas can be cleaned and used directly as a fuel or synthesis gas. For SNG, this gas is then compressed and shifted. Gas from the shift converter is purified, methanated, dehydrated and compressed to pipeline levels. Thermal efficiency is 75%.

STATUS: This process was developed in Europe over fifty years ago. The process was constructed commercially at 16 plants in a number of countries, using a total of 36 generators. These plants are still operating with the largest having an output of 1.1 million scfd. The plants produce low BTU fuel gas (with air instead of oxygen) and synthesis gas for the production of methanol, ammonia, and oil by Fischer-Tropsch synthesis. The largest commercial sized plant is 18 feet in diameter and processes 700 TPD coal using air or 1000 TPD using oxygen.

The last installation was in 1960, however, the process is once again under consideration for current installation, along

THE BDM CORPORATION

with Lurgi, Koppers-Totzek and Wellman-Galusha processes. Davy Powergas Inc. is currently developing a high-pressure modification of the Winkler process which should increase the thermal efficiency. (1978)

THE BDM CORPORATION

59. TITLE: WILPUTTE PRODUCER

OWNER/DESIGNER: Wilputte Corporation, Murray Hill, N.J.

DESCRIPTION: This gasifier is produced in various forms to accommodate different feedstocks. Coal is fed downward to a fixed-bed where it is gasified by partial combustion with moist air passing upwards through the bed. Ash is withdrawn by a rotating grate at the bottom of the unit.

STATUS: Commercially available gasifier with a capacity of 30 TPD of coal to produce 3.5-4 million scfd of 150-170 Btu/scf gas. The Holsten Defense Plant operates a Wilputte gasifier in Kingsport, Tennessee. (1978)

THE BDM CORPORATION

60. TITLE: WOODALL-DUCKHAM/GAS INTEGRALE

OWNER/DESIGNER: Babcock Contractors, Inc.

Pittsburgh, Pennsylvania,

(holder of U.S. process license)

DESCRIPTION: Coal is crushed to 3/8" to 1-1/2" size. The coal is fed into the top of the gasifier. There are two takeoffs for the gas. The top gas offtake temperature is controlled to about 250°F by regulating the quantity of gas so that the raw coal is not suddenly exposed to a high gas temperature. The gases leave the lower exit at approximately 1200°F. As the coal descends, it is gently heated by rising hot gases which drive off water vapor, coal gas, oil, and tar and convert the coal to semi-coke.

The distillation products exit in the top gas stream at 250°F. The semi-coke reacts with a steam-air-oxygen blast and is completely gasified, leaving ash. A cyclone removes tar particles from the top gas while a cyclone removes dust from the lower gas stream. The two gas streams then recombine to form a gas stream at about 750°F which is then distributed. The gas produced is low-Btu gas at approximately 175 Btu/scf. The process normally operates at atmospheric pressure and with air, although it is suggested oxygen can be used. It has an estimated thermal efficiency of 90%.

STATUS: At present there are over 100 of these gasifiers in commercial operation outside of the U.S. The Wood all Duckham-process is being constructed by the General Refractories Company as part of DOE's "Gasifiers in Industry" program. The process is being used to produce fuel gas for helms at its plant in Hetchins, Kentucky. The demonstration plant will use 2 TPH of coal. It is scheduled for start-up in 1981. (1978)

THE BDM CORPORATION

APPENDIX B

CATALOG OF MODELS,
ANALYTICAL METHODOLOGIES

THE BDM CORPORATION

PART I
STEADY STATE FLOW SHEET SIMULATION

THE BDM CORPORATION

1. TITLE: AGPSS

CONTACT: Prof. Brice Carnahan
Chem. Eng. Dept.
U. of Michigan
Ann Arbor, MI 48104

DESCRIPTION:

A highly interactive system that allows the user to create flowsheets at a graphical terminal (either refresh or storage tube) and then to monitor and display the results of steady-state simulation. The computational load is handled on the central computer (an AMDAHL 470/V6), and the simulation is a PACER-like system with a physical property system (similar in structure to the one in the CHESS simulator). The system uses a relational data structure for both process and picture information, and the executive system is organized around a set of routines to implement set operations in structure.

THE BDM CORPORATION

2. TITLE: ASPEN

CONTACT: Dr. Paul Gallier
ASPEN Project Manager
MIT
Cambridge, MA
Department of Chemical Engineering and
Energy Laboratory

DESCRIPTION:

ASPEN (Advanced Systems for Process Engineering) is a computer based process simulator and economic evaluation system for use in the engineering of fossil conversion processes. When completed, it will be capable of performing detailed material and energy balances, equipment sizing, and economic evaluation for processes such as coal gasification and liquification. Features will include an extensive data base for coal physical properties, compatibility with conversion reactor models currently available and/or being constructed, and the capability of handling streams containing solids.

VALIDATION:

Validation will begin in October 1979 when the completed system will be available to industry on a test basis.

AVAILABILITY:

The system will be available on a test basis in October 1979 and the object code will be for sale the following summer.

DOCUMENTATION:

There is extensive documentation in the form of quarterly and annual reports as well as published papers.

REFERENCES: 1, 2, 3,

THE BDM CORPORATION

3. TITLE: ChemE Simulator

CONTACT: Roy L. Rowell
Petrochem Consultants, Inc.
P.O. Box 26901
Houston, TX 77207

DESCRIPTION:

The inputs are: a) component properties; b) process flow-plan (connected sequence of process calculations, tower stages, etc.); c) unit operating instructions as to temperatures, or pressures, or heat inputs or product-purity requirements from distillation towers. The outputs are: a) all equilibrium process temperatures, recycle flowrates and heat duties; b) when needed, compressor brake horsepower requirements; c) distillation, tower-reflux product-split requirements to achieve a specified product purity; as well as the "relative" diameter requirements of each stage in each tower; d) various units of stream flow and properties (at both standard and operating conditions) for all segments of the flow-plan; and e) analyses of each stream in the defined flow-plan. In summary, the output will provide a definitive heat-and-material balance design (or evaluation) of the user-described processes for a wide range of system complexity.

THE BDM CORPORATION

4. TITLE: Chemical Engineering Simulation System (CHESS)

CONTACT: R. L. Motard
Dept. of Chem. Eng.
U. of Houston
Houston, TX 77004

DESCRIPTION:

This is a complete flowsheet simulation system. An integrated thermophysical property package handles ideal and nonideal organic systems in single-or two-phase. The system includes both short-cut and rigorous fractionator and absorber calculations, pumps, compressor/expanders, heat exchangers, control blocks and reactors.

THE BDM CORPORATION

5. TITLE: Chemical Process Simulator

CONTACT: Prof. Jude T. Sommerfield,
School of Chem. Eng.
Georgia Institute of Technology
Atlanta, GA 30332

DESCRIPTION:

Simulates chemical processes, using (primarily) shortcut methods for both unit operations and physical properties. Input data consist of component list, feed and estimated recycle streams, and equipment parameters. Physical-properties library contains approximately 130 components. Output consists of complete process material balance and various equipment parameters.

THE BDM CORPORATION

6. TITLE: CHEMOS

CONTACT: D. W. Thompson,
Prof. and Acting Head
Chem. Eng. Dept.
U. of British Columbia
Vancouver, B.C., VGT 1W5
Canada

DESCRIPTION:

Flowsheet modeling (steady state) and optimization. Associated properties program calculates PVT, V-L equilibrium, and thermal properties. Inputs are parameters for unit blocks representing process equipment or specifying recycle or feedback control loops, statements that specify stream connections, and program control commands. Outputs are stream flows that specify stream connections, and program control commands. Outputs are stream flows (tonnes/day), energy flows (kW), pressures (kPa), temperatures (°C) and operating and capital costs. Internal data are in strict SI units. The program is intended as an aid to teaching modeling and design. Students write programs to represent simple process-equipment blocks as part of 4th-year elective and graduate courses.

THE BDM CORPORATION

7. TITLE: Computer Aided Design Flow-Sheeting Program Design
(SUCES)

CONTACT: Prof. R. G. H. Prince
Dept. of Chem. Eng.
U. of Sydney
Sydney, N.S.W. 2006
Australia

DESCRIPTION:

Solves the steady-state heat and mass balances around a chemical processing plant. It employs user-defined subroutines to model the processing units within the plant, while the executive routine takes care of all the housekeeping in passing information between units. The main power of SUCES lies in its ability to generate an efficient order of calculation of a flowsheet as well as in its ability to handle the convergence of recycle streams, in a user-transparent fashion. Currently, four convergence routines are used by SUCES: dominant Eigen-value, Wegstein acceleration, successive substitution and quasi-Newton techniques.

THE BDM CORPORATION

8. TITLE: CONCEPT

CONTACT: Dr. Mike E. Leesley, Director
The Concept Group
Chem. Eng. Dept.
U. of Texas
Austin, TX 87812
or Dr. P. Winter, Head
Chemical Engineering Group,
Computer Aided Design Center
Madingley Road
Cambridge, CB3 0HB
England

DESCRIPTION:

A computer-aided process-design and simulation package. The process is modelled using a number of interconnected programs: A model of the plant is set up in the FLOWSHEET phase, and this flowsheet is analyzed for recycle loops and iterate streams by the LOOPFINDER and ITFINDER routines. Process data are input in the DIALOGUE phase, and the heat and mass balance simulation is run by the MASTER CALCULATOR. Interactive facilities are available in FLOWSHEET and DIALOGUE phases, so that modifications can be made and the results evaluated very rapidly. Comprehensive physical property data are available from the associate THERMOPAKS, and most commonly used unit operations can be simulated using the unit subroutine library. There are also facilities for the user to provide his own unit subroutines or physical-property data.

THE BDM CORPORATION

9. TITLE: DESIGN

CONTACT: Lawrence J. Lesser
Vice-President, Marketing
ChemShare Corp.
P.O. Box 6706
Houston, TX 77005

DESCRIPTION:

Simulates chemical and petroleum processes, and calculates complete steady-state material and energy balances. ChemShare has been adding coal liquefaction modeling capabilities to DESIGN in response to requirements specified by the ChemShare user community. Many common unit operations are available as standard-equipment modules and are accessed automatically. User can easily include his specialized or proprietary modules as desired. Thermodynamic properties for 100 standard components plus petroleum fractions and other organic chemicals are provided automatically; nonstandard components can be handled with necessary parameters supplied. Other special features include automatic recycle calculation with convergence acceleration, restart capability, and an economics package for costing equipment and preparing a design report (including probability and sensitivity analyses). Featured is simplified data-input method.

THE BDM CORPORATION

10. TITLE: EBP-II

CONTACT: G. V. Reklaitis, Assoc. Prof.
Purdue University
Dept. of Chem. Eng.
West Lafayette, IN 47907

DESCRIPTION:

A general-purpose, preliminary energy-balancing and flow-sheet/energy-balance simulation program that uses linear, elementary unit modules but can accommodate linear constraints. The three general types of constraints allowed are linear constraints involving heats transferred, stream enthalpies or stream temperatures. A physical-properties estimation library is not provided. The user must supply heat capacities, heat of transition, and heats of reaction--all at a user-selected reference temperature. Program output includes an echo of all input data, notes on how the solution was obtained, calculated values of module parameters not specified as part of input, and a complete tabulation of the flowsheet stream table, including stream temperatures and enthalpy flows.

THE BDM CORPORATION

11. TITLE: Energy Balance for Dual Purpose Power Plant (ENGBAL)

CONTACT: Dale W. Kirmse

Chem. Eng. Dept.

U. of Florida

Gainesville, FL 32611

DESCRIPTION:

Provides energy and steam balances for dual-purpose power plants. Consists of a set of subroutine modules (turbines, boilers, heat exchangers, connectors, etc.), driver-system subroutines and steam-table subroutines. These can be connected by subroutine calls in a manner similar to FLOWTRAN. Module parameters and initial estimates of streams are input under a name-list format. Output is system energy and steam balance, energy requirements, and operation descriptions of each module.

THE BDM CORPORATION

12. TITLE: EXEC

CONTACT: Dr. F. A. Meijer
Delft University of Technology
Laboratory of Chemical Technology
Julianalaan 136
Delft
The Netherlands

DESCRIPTION:

A flowsheet program that performs steady-state simulation of chemical plants, as well as design and equipment sizing. It consists of two parts, EXEC1 and EXEC2; EXEC 1 determines the optimal calculation order of the units in the flowsheet according to the methods of J. C. Tiernan, and W. Lee, and D. F. Rudd. EXEC2 performs the actual simulation. Convergence of recycle streams is established by the method of O. Orbach and C. M. Crowe. No physical property databank is attached. Process units are written as separate subroutines. The system is solid in the sense that extensive error checking is done on input data and in all stages of the calculation. Several typical unit operations are already included as subroutines and others are under development.

THE BDM CORPORATION

13. TITLE: FAST

CONTACT: R. B. Stein
Globe Engineering Co.
184 Aptos Ave.
San Francisco, CA 94127

DESCRIPTION:

All purpose study program to do any thermodynamic operation in hydrocarbon service. Linked, successive operations are permitted. Can handle up to 50 components from an internal list of 100 of the most-common, pure components (including non-condensables and water) or up to 50 petroleum fractions or any combination thereof. Water is allowed for in flashes. Thermodynamic functions are generally based on the ASI '64 Green Handbook, but have been extensively modified to cover highly nonideal mixtures encountered in ethylene plant service. Typical operations include: dew and bubble points, isentropic, isenthalpic or isothermal flashes, flash at fixed percent vaporization, flash curves, centrifugal compressor, distillation, chemical reactors, etc. Inputs are from punched cards; output is 120-column line-printer text. Constraints are a maximum of 50 components in any feed and operating conditions between -250°F and +2,200°F and 0 to 7,000 psia.

THE BDM CORPORATION

14. TITLE: FLOWSIM

CONTACT: Heinrich Bakemeier
Abt. FOD/N BASF AG
Marienstre. 8, D 6700
Ludwigshafen
West Germany

DESCRIPTION:

A completely integrated set of programs to perform material and energy balances for simulating stationary chemical plants. To facilitate operation it has its own user-oriented language. For the common unit-operations in chemical plants, subroutines are kept in library, and the user can add his own programs. The thermodynamic data are taken from its own data bank. The maximum number of streams is 100, the maximum number of components in each stream is 30. The FLOWSIM system automatically finds the minimum number of cycles and offers the user different methods for accelerating convergence. Up to now there is no equipment sizing available, but there is an overall investment cost estimation. Optimization of single units and parts of the plant with several parameters and constraints is possible. A block diagram of the plant can be plotted separately.

THE BDM CORPORATION

15. TITLE: FLOWTRAN

CONTACT: Monsanto Co.
800 N. Lindbergh Blvd.
St. Louis, MO 63166

DESCRIPTION:

The system comprises four major programs: 1) FLOWTRAN Process Simulator; translates the FLOWTRAN description of a process flowsheet into computer programs, which it then executes 2) PROPTY Physical Property Program; takes raw property-data and computes constants for physical property correlations used in the FLOWTRAN simulator 3) VLE Phase Equilibria Program; takes raw phase equilibrium data and computes parameters for liquid-phase activity-coefficient correlations used in the FLOWTRAN simulator 4) INF Information Retrieval Program; stores the physical property constants from PROPTY in a public or private data file and subsequently retrieves them for use by the FLOWTRAN simulator. Data for 180 chemical species (components) are stored in the public data file.

THE BDM CORPORATION

16. TITLE: General Engineering and Management Computation System
(GEMCS)

CONTACT: Dr. A. I. Johnson, Prof. and Dean
Faculty of Engineering Science
U. of Western Ontario
London, Ontario, Canada

DESCRIPTION:

A general purpose systems simulator based on a modular approach and sequential iterative computation procedure.

THE BDM CORPORATION

17. TITLE: General Process Simulator (GPS II)

CONTACT: Francis Muncastor
McDonnell-Douglas Automation Co.
St. Louis, MO 63166
(314) 232-2583

DESCRIPTION:

This Phillips Petroleum Corporation computer-aided, process-design system calculates heat and material balances. The engineer is not required to use a programming language; he only lists process specifications for each unit in his plant, and the desired calculational sequence through the plant. Physical and thermodynamic data are accessed by the program's Phillips physical-data system, where several types of each physical property are available. For example, the data system makes available 12 types of vapor-liquid-equilibrium data. The engineer may use either shortcut or rigorous mathematical models to characterize process units. In addition, flexibility modes allow for logical decisions during program execution: i.e., flow changes, stream and note data changes, convergence on temperature or stream composition are possible.

THE BDM CORPORATION

18. TITLE: GPFS

CONTACT: David H. Augenblock
Suntech, Inc.
1608 Walnut St.
Philadelphia, PA 19103

DESCRIPTION:

Mathematical solution of the steady-state heat-and-material balances for a process made up of one or more unit operations. Input is description of the process flowsheet (including units operations, chemical components, operating conditions). Outputs are overall heat-and material-balance summary and total description of solution for each unit operation. Can handle recycle, multiple problems (base case and changes in specifications); no feedback control capabilities.

THE BDM CORPORATION

19. TITLE: MBP-II

CONTACT: G. V. Reklaitis, Assoc. Prof.
Purdue University
Dept. of Chem. Eng.
West Lafayette, IN 47907

DESCRIPTION:

A general-purpose, mass-balancing and process simulation program that uses linear, elementary unit modules but can handle linear and nonlinear equality constraints. The solution procedure employs a novel mixer-equation approach under which only as many equations must be solved simultaneously as there are tear streams that would have to be converged in the conventional sequential-modular approach. Constraints are accommodated by generating parametric solutions. Input requires description of the flowsheets in terms of four elementary modules, each with its module parameters. Three general types of constraints are allowed. The user may specify system of units. Output consists of echo of input data, notes of how the solution was obtained, calculated values of module parameter that had not been specified by the user, and a complete tabulation of the flowsheet stream table.

THE BDM CORPORATION

20. TITLE: MOSES (Modelling System for Engineering Studies)

CONTACT: N. Peter, SACDA
Eng. Science Bldg.
U. of Western Ontario
London, Ontario, Canada
N6A 5B9

DESCRIPTION:

Contains models of the following processes and allows users to add constraints to be solved with the processes: global modelling and simulation of chemical processes; solution of mass balances in chemical processes; solution of mass balances in pulp mills; solution and optimization of large sets of non-linear algebraic equations. All the equations are solved simultaneously.

THE BDM CORPORATION

21. TITLE: MPPM

CONTACT: IR&T Corporation
McLean, Virginia 22101
(R. W. Roig, Project Manager)

DESCRIPTION:

A MPPM (Materials-Process-Product-Model) of coal-process technology is an application of methodology for systematically analyzing an array of competing manufacturing technologies from economic, environmental, and energy policy perspectives. The model consists of:

- (1) A data base for coal-related materials and coal conversion processes;
- (2) An algorithmic structure that facilitates systematic evaluations in response to exogenously specified variables such as tax policy, environmental limitations, and changes in process technology and costs.

The model has been developed as an interactive program, with flexibility for inclusion of new process data, revision of old data, and specification of exogenous data related to policy options.

VALIDATION:

This model has been given comparable results with other models for hypothetical situations, but it has not yet been applied to full scale facility.

AVAILABILITY:

The model is operation on the DOE computer in Germantown, MD.

THE BDM CORPORATION

DOCUMENTATION:

The development of the model is documented in periodic project reports and user documentations from IR&T.

REFERENCES: 4, 17

THE BDM CORPORATION

22. TITLE: PATT

CONTACT: Sigfried Nagel Dr.
Bayer AG
Bayerwerk IN AP-AM 1
D-509 Leverkusen
West Germany

DESCRIPTION:

The system is designed to: simulate individual units and networks (e.g., distillation columns, reactors, heat exchangers, etc.); compute the flowsheet balance; solve design problem (e.g., McCabe-Thiele procedure); and compute discontinuous processes (e.g., batch distillation).

THE BDM CORPORATION

23. TITLE: PROCESS

CONTACT: Ron Janney
Chief Systems Eng.
Dravo Corp., Dravo Bldg.
1250 Fourteenth Street
Denver, CO 80202

DESCRIPTION:

A simulation program designed to perform steady-state mass balances on chemical and metallurgical process flowsheets. Operational nodes are used to structure the flowsheet. The available nodes are: (1) Addition node--up to five streams combined to one; (2) Separation node--one inlet and two outlet streams determined by fractional split; (3) Distribution node--one inlet and two outlet streams determined by component distribution coefficients; (4) Reactor node--one inlet and one outlet stream determined by reaction coefficients and fractional conversion. Process loops and recycle streams can be quickly solved. Output includes total flowrate, component flowrates, aqueous species concentrations, stream percent solids, liquids and gases, and slurry specific gravity for each process stream defined.

THE BDM CORPORATION

24. TITLE: Process Analysis System

CONTACT: Prof. John H. Erbar
School of Chem. Eng.
Oklahoma State U.
Stillwater, OK 74074

DESCRIPTION:

Accepts a process flow definition, and process equipment parameters. Performs heat-and-material-balance calculations for recycle or nonrecycle processes. Automatic recycle detection and closure. Contains standard suite of unit operations applicable to petroleum industry. Three methods of predicting thermodynamic properties (CS, GS, SRK). Output consists of complete list of input data, iteration record, process-element material balance plus H&M sheets. If appropriate, diagnostics are printed for bad input data, unreasonable process specifications, excursions beyond correlation limits, etc. Handles up to 200 streams, 100 unit operations.

THE BDM CORPORATION

25. TITLE: Process Design Analysis, Phillips Petroleum Co. Program Package I (PDA)

CONTACT: Francis Muncastor

McDonnell-Douglas Automation Co.

St. Louis, MO 63166

(314) 232-2585

DESCRIPTION:

Designs or simulates complete plants, or studies characteristics of one or more process units. It is used for preliminary or final calculations of heat-and-material balances with help of high-level process-oriented language. Physical properties are accessed from Phillips physical-data system, which is an extensive data program that provides several types of each physical property (for example, several types of liquid equilibrium data are given). Over 200 hydrocarbons are included in the data base. If economic calculations are required, PDA sizes and estimates cost of equipment, accumulates utilities and evaluates economic indicators. Other subroutines provide for linear programming, curve fitting and matrix operations. PDA has built in flexibility. In a given stream vector of 30 elements, the user has complete freedom in designating any of the components (i. e., one could be a given density, another a completely different property of a different substance). Also user FORTRAN subroutines can easily be added for more specific modeling of particular components.

Phillips has been providing simulations for the petroleum industry since 1971 (having begun R&D for those simulations in 1963). Phillips currently has two clients (one in research, the other in private industry) using PDA in conjunction with coal gasification.

THE BDM CORPORATION

26. TITLE: Process Optimization System (PROPS)

CONTACT: J. L. Gaddy, Assoc. Prof.
Chem. Eng. Dept.
U. of Missouri
Rolla, MO 65401

DESCRIPTION:

Flowsheet simulator with economics, optimization and reliability capabilities. These capabilities include equipment sizing, cost estimation, economic evaluation, optimization with choice of algorithms and/or process reliability analysis.

THE BDM CORPORATION

27. TITLE: Process Simulation Executive (PSX)

CONTACT: Hideo Sadotomo
Senior Process Engineer
Mitsui Toatsu Chemicals, Inc.
2-5 Kasumigaseki
3-Chome, Chiyoda-ku
Tokyo 100, Japan

DESCRIPTION:

A steady-state flowsheeting program for the detailed design and performance analysis of general chemical processes. Significant features of PSX are: a modular approach in process construction, program libraries for unit calculations and physical property calculations, automatic calculation ordering, and a flexible interface in input and output of unit modules.

THE BDM CORPORATION

28. TITLE: Simulation Program PROCESS

CONTACT: Vincent Vermeuil or James Byrne
Simulation Sciences, Inc.
1440 N. Harbor Blvd.
Fullerton, CA 92635
(714) 879-9180

MODEL:

Performs rigorous mass and energy balances. Unit operation modules available to simulate all process units typically encountered in the hydrocarbon, chemical and petrochemical industries. Unit operations can be combined and ordered in building-block fashion to simulate processes of any degree of complexity. Process constraints can be input as either maxima or minima, or specific desired quantities. A full spectrum of thermodynamic correlations is included with proven accuracy over a wide range of temperature and pressure. It also has an extensive pure-component data bank with fully detailed physical properties of more than 600 components. Input is free format and convenient for teletypewriter or CRT (cathode-ray tube) users. Program accepts British or SI units of input. Output is formatted and paged for easy display on CRT or teletypewriter. Main features: (1) User may add his own unit operation subroutines, proprietary thermodynamic correlations, or component data; (2) Energy balance may be suppressed for preliminary mass balance studies; (3) Automatic restart and case studies capabilities are provided. For input one characterizes the coal and reactor of whatever component is involved. There is no specification of the type of gasifier to the simulator. One simply provides the appropriate input data for the gasifier in question (e.g., throughput, temperature, etc.) and the calculation proceeds as usual. The output includes streams data, temperatures, heat

THE BDM CORPORATION

balance, horsepower of pumps and compressors, etc. The program can simulate 75 units and 250 streams.

The model is an "engineer's tool" in that it has the capability of modifying the program, such as performing additional recycles, as it runs. Other features include a restart and zoom which allows the user to simulate one part of the plant while keeping others stationary.

Neither economic nor raw data such as properties of coal have been incorporated into the program.

SSI has investigated modifications to PROCESS in order that it be able to perform the particular functions involved in modeling a coal gasification plant, including a three phase quench unit with electrolyte dissociation in the liquid water phase.

VALIDATION:

The programs have been extensively tested by Ashland Chemicals and other users. Ashland in particular has implemented the simulation in designing a plant which should be on line this summer.

AVAILABILITY:

The system is accessible from over 20 time sharing networks, and can be leased from SSI for use on an in-house computer.

DOCUMENTATION:

User manuals are available from SSI and time sharing networks offering the SSI system.

REFERENCES: 18, 19

THE BDM CORPORATION

29. TITLE: Program for Chemical Plants Simulation (SIMUL-UNT)

CONTACT: V. J. Koppel, Chem. Eng.
Universidad Nacional
Casilla Correo 1
Sucursal 2
Tucuman
Argentina

DESCRIPTION:

Calculates material balances of continuous processing plants. The plant is codified in matrix-type form; in additional matrices, inputs and outputs are also codified. Individual units are expressed as unit computations. Program gives material balances of the whole plant, of every flow and of every component, for straight or recycled processing systems, accepting any number of recycle loops. Calculation is performed with acceleration procedures. It is adapted mainly for material balances.

THE BDM CORPORATION

30. TITLE: RHONE-POULENC INDUSTRIES PROGRAM PACKAGE

CONTACT: Secretariat du Calcul
Scientifique
Rhône-Poulenc
Centre Regional de Paris
Rue Maximilien Robespierre
-Batiment F.
94120 Fontenay sous Bois
France

DESCRIPTION:

This includes several hundred programs in the fields of chemical engineering, statistics, and engineering. The programs are classified as follows:

- (1) physical and chemical properties-calculations for pure compounds and mixtures;
- (2) installation balances and chemical kinetics-heat and mass balances of particular processes, reactor calculations;
- (3) heat transfer-equipment with tubes and vessels, equipment with graphite blocks, compact equipment, miscellaneous heat-exchange units;
- (4) mass transfer-theoretical plate calculation, distillation, absorption, extraction, adsorption;
- (5) hydrodynamics-distillation and absorption plates, dimensioning of phase separators;
- (6) engineering-material management and resistance; economics calculations;
- (7) analysis and predictions;
- (8) statistics, optimization programs, prediction methods;
- (9) miscellaneous-numerical analysis, information service programs, documentation.

THE BDM CORPORATION

31. TITLE: RUMBA

CONTACT: Ivan V. Klumpar
Group Leader
Kennecott Copper Corp.
128 Spring St.
Lexington, MA 02173

DESCRIPTION:

The proposed Rudimentary Material Balance (RUMBA) program can model any process using five modules that are defined by a type number and the following data: (1) Addition module - 5 inlet and 1 outlet stream numbers; (2) Conversion module - 1 inlet and 1 outlet stream number, key reactant number, its fractional conversion, and stoichiometric coefficients; (3) Separation module - 1 inlet and 2 outlet stream numbers, fractional split; (4) Distribution module - 1 inlet and 2 outlet stream numbers and component distribution coefficients; (5) Loop module - loop number, recycle stream number, module number to which it is recycled, key component number, maximum number of iterations and key component accuracy required. Once the modules are defined, RUMBA can calculate any number of unknown streams based on an appropriate number of known streams that are specified in terms of component flowrates. Nested and intersecting loops and other intricate flowsheet features can be handled.

THE BDM CORPORATION

32. TITLE: SEPSIM

CONTACT: Prof. Peter Silveston
Dept. of Chem. Eng.
U. of Waterloo
Waterloo, Ontario, Canada

DESCRIPTION:

A stripped-down heat-and-mass balancing program designed for use in simulating relatively simple systems. In the version that is in use at the University of Waterloo and which has been distributed to some consulting engineering firms, simulation is directed at waste treatment plants handling both municipal and/or industrial wastes. Inputs to the program are in the composition, condition and flowrates of the feed streams, the names of the computer models to be used in simulating each unit in the process, the description of the network connecting the process units, a list containing the parameters used in the models and finally some relatively crude information to permit the executive program to undertake iterative closing of the heat and mass balances. Outputs of the program are the composition and conditions and flow rates in each stream of the process. In addition, some information about the parameters used or calculated from data given is retrievable as well as some description of the calculations initiated by the simulation program. The program is constrained as to the size of the network it can handle. It is not a particularly efficient program as it was written as a means of illustrating the operation of computer-simulation and computer-aided design systems. Its primary application has been to waste-treatment systems that are relatively simple. A small program accompanies the executive. This program accepts data furnished by a user and checks to see whether they can be handled by the program.

THE BDM CORPORATION

33. TITLE: Steady State Simulation System

CONTACT: G. V. Reklaitis, Assoc. Prof.
Purdue University
Dept. of Chem. Eng.
West Lafayette, IN 47907

DESCRIPTION:

A flowsheet simulation system that can accommodate pure-component, boiling fraction and solid-component flows and information. It employs a compressed storage scheme for stream and equipment parameter vectors and uses the sequential-modular computation strategy. The system is integrated with the PPROPS physical properties system (417) and the PCOST costing and economics package (397). A library of conventional unit-operations modules such as venturi scrubber, electrostatic precipitator, and ejector. Input required includes connection information, equipment parameters, species identifiers, as well as input and tear stream estimates. Data validation is carried out. Output consists of equipment parameter summaries and stream tables.

THE BDM CORPORATION

34. TITLE: SIMUL

CONTACT: Prof. P. Benedek
Computer Application R and D Center of the Chemical
Industry
Velgyipari Szamitas-technikai Fejlesztési Társaság
H-1393 Budapest
P.O. Box 319, Hungary

DESCRIPTION:

A computer program system that simulates many industrial unit operations of chemical plants. The modular system is designed for use by process engineers who do not have the assistance of computer specialists. It is especially useful for the steady-state analysis of several design alternatives of complex chemical systems. The flowsheeting program system has a large physico-chemical properties data base. The system's input and output data are phrased in engineering terms.

THE BDM CORPORATION

35. TITLE: Simulator for Process Analysis and Design (SPAD)

CONTACT: Prof. Richard R. Hughes
U. of Wisconsin
411 Egeineering Research Building
1500 Johnson Drive
Madison, WI 53536

DESCRIPTION:

A simplified steady-state process simulator, prepared for use in instruction. Accordingly, the various blocks are all based on shortcut methods. Moreover, the physical data bank is quite simple in format and currently limited to six components - those used in the example problem. It is quite easy to add both additional components and additional unit blocks to the system. One unique feature is the use of points as well as streams. This accomplishes the same purpose as the referencing method used in some other simulators.

THE BDM CORPORATION

36. TITLE: SYMBOL and SYMBOL-WITH-BOUNDS

CONTACT: Dr. P. Winter, Head
Chemical Engineering Group
Computer Aided Design Centre
Madingley Road
Cambridge CB3 0HB
England
or
Dr. Mike E. Leesley
The Concept Group
Chem. Engr. Dept.
U. of Texas
Austin, TX 78712
or
H. P. Hutchinson
U. of Cambridge
Dept. of Chem. Eng.
Pembroke Street
Cambridge CB2 3RA
England

DESCRIPTION:

Mass balancing and process simulation using simple linear models and a simultaneous solution procedure that can handle equality constraints with great ease. Has been in use as a teaching aid for many years. Input requires description of the process by units from a strictly limited repertoire, and description of the behavior of these units by linear parameters. Output is a printed description of the mass flows in all the interconnecting streams. SYMBOL-WITH-BOUNDS is similar to SYMBOL but accepts parameters whose values are restricted within upper and lower bounds. Optimization of a linear objective function is possible, or the bounds of all the mass flows may be obtained.

THE BDM CORPORATION

37. TITLE: Syntha II

CONTACT: James E. Howell, Jr.
Sr. Consultant
Utilities Service Center
Control Data Corp.
6003 Executive Blvd.
Rockville, MD 20760

DESCRIPTION:

Performs heat and material balance calculations for any arrangement of components found in a fossil or nuclear steam-power plant or in coal gasification systems or combined cycles. Can analyze operating data for startup and/or normal performance problems. Input data include component configuration and component performance characteristics. The output includes full thermodynamic characterization of all steam/water and gas streams, full characterization of component performance (at any load), and overall system performance. SYNTHA II has been used in conjunction with coal gasification plant designs by Ralph M. Parsons Co., NASA Lewis, and Combustion Engineering among others.

AVAILABILITY:

SYNTHA II is currently being marketed by Control Data Corporation. Extensive guidance in the use of SYNTHA II is provided as part of the overall service package.

DOCUMENTATION:

User manuals are available from Control Data Corporation.

REFERENCES; 20, 21, 22

THE BDM CORPORATION

38. TITLE: Syntha III

CONTACT: David W. Hutchinson, Pres.
Syntha Corp.
41 West Putnam Ave.
Greenwich, CT 06830

DESCRIPTION:

Power Plant Syntha III computes design, off-design and part-load performance of process utility systems and co-generation power plants of any complexity. Convenient input data consist of: (1) Piping or process flow diagram in numerical form; (2) Individual steam, heat and power requirements for each user; (3) Individual-component performance specifications for each pipe, valve, pump, compressor, turbine, combustor, heat transfer component, motor, generator and power plant control; (4) Optional selection of up to 20 items of input data to be altered by Syntha III to achieve up to 20 performance specification. Output data include: (1) All water, steam and gas stream flows, temperatures, pressures, etc.; (2) Individual component performance and sizing; (3) Total fuel and heat requirements, electric power summary, steam and cooling water requirements.

THE BDM CORPORATION

39. TITLE: TISFLO

CONTACT: J. A. de Leeuw den Bouter
Research and Patents, DSM
PO Box 18, Geleen
Netherlands

DESCRIPTION:

Forms part of the TIS program developed by DSM for computation in the field of process calculations. The TISFLO package is specially designed for calculations on flowsheets, viz. the following three operations: (1) Flowsheet simulation: Calculation of the steady-state mass and/or heat balance for an arbitrary sequence of process steps. The problem is solved by the simultaneous approach. Non-linear relations are processed using a first-order approximation. For simulation, the flowsheet would be exactly determined, i.e., the number of equations should be equal to the number of unknowns. (2) Balancing of redundant data: For this operation, several data of the flowsheet simulation problem are redundant sets of measuring data. By assigning correction terms to the measuring data and adding a criterion for determining these terms, the system is again exactly determined. The weighting factors of the measuring data are accounted for in the criterion. (3) Optimization: In the data set of the flowsheet simulation problem, some of the data are removed. By addition of constraints and an object function, the total system is again exactly determined.

THE BDM CORPORATION

PART II
GASIFIER SIMULATIONS

THE BDM CORPORATION

1. TITLE: Coal Gasification Simulator

CONTACT: T. R. Blake
Systems Science Software
La Jolla, CA
(714) 453-0060

DESCRIPTION:

Simulators have been developed for fluidized bed and entrained flow coal gasifiers. The fluidized bed has a two phase representation. Inputting the mixing process and kinetics the output is in an input/output description. The program simultaneously solves mass, momentum, and energy balance for gas and solids in the reactor. This requires a prescription for the composition of the materials and their chemical and physical interactions. The result would be predicting the hydrodynamics and chemical behavior. Finite elements techniques are used in the modeling.

H_2S and NH_3 clean up systems are also modeled.

VALIDATION:

There are comparisons between parts of the model with a fluidization lab mixing process. Two fluidized bed models developed by DOE and an entrained flow stream bed gasification plant for TEXACO at Montebello, California should give further data for model comparison.

AVAILABILITY:

The DOE will be provided with codes and a user's manual for two fluidized bed gasifiers. This would be accessible at Morgantown.

REFERENCES: 23

THE BDM CORPORATION

2. TITLE: DYNAMICALLY MODELED COAL GASIFICATION SIMULATOR

CONTACT: Dr. Scheisser
Lehigh U.
Bethlehem, Penn.
Dept. of Chem. Eng.
(215) 861-4264

DESCRIPTION:

A dynamically modeled entrained flow gasifier has been developed. It is one dimensional in space, and evolves in time. Transport coefficients take turbulence and convection into account. The model is for an entrained flow gasifier assuming perfect mixing. A series of models have been developed.

VALIDATION:

The model is not validated in that a prototype has not been built. The programs used are based on equations taken from the literature.

AVAILABILITY:

A series of models are available, but they would present only a starting point in modeling a prototype plant.

DOCUMENTATION:

Additional information is available from DOE TIC at Oak Ridge.

THE BDM CORPORATION

3. TITLE: Fixed Bed Coal Gasification Simulator

CONTACT: T. F. Edgar
U. of Texas
Austin Texas 78712
Dept. of Chem. Eng.
(512) 471-5238

DESCRIPTION:

Fixed Bed Gasifer.

- (1) An algebraic version has been developed utilizing a simple program requiring a nonlinear equation solving package. It can handle 8-10 components in a process. It gives steady state energy and material balances. A one dimensional model, it does not handle turbulent flow. Inputting actual data for fixed bed gasifiers, it would give limited information on materials and wastes. In this case one would have to specify heat losses from the reactor itself in addition to flow being considered by the model.
- (2) A differential equation model has been developed which solves differential equations by integration to give temperative and composition profiles.

According to Dr. Edgar, a major difficulty, common to all gasifier models, is the requirement to specify characteristics of the coal sufficiently to describe and hence predict its behavior.

VALIDATION:

There has been some success in trying to match actual results using reported data from fixed projects.

AVAILABILITY:

The model is available at a modest cost.

REFERENCES: 7

THE BDM CORPORATION

4. TITLE: Fluidized Bed Gasifier

CONTACT: H. S. Caram
Lehigh U.
Bethlehem, Penn.
Dept. of Chem. Eng.
(215) 861-4259

DESCRIPTION:

Models have been developed for the kinetics of coal reactions in a fluidized bed steam/O₂ gasifier. The dynamic behavior is modeled. The model consists of a package which includes a series of units such as the gasifier, methanator, pyrolysis units, gas absorption, etc. A model for a Winkler gasifier has been developed but not run.

VALIDATION:

The above packages have been used on the IFT pilot plant and a Rayleigh, N.C. fluidized bed reactor. Data obtained for small pilot plant (8" diameter gasifier) is not readily applicable to a prototype plant.

AVAILABILITY:

The models are available for \$1200.

REFERENCES: 13, 14, 16

THE BDM CORPORATION

5. TITLE: General Gasifier Modeling

CONTACT: C.Y. Win
U. of W. Va.
Morgantown, Va.
Dept. of Chem. Eng.
(304) 293-2111

DESCRIPTION:

General models for coal gasifiers have been developed. Types of applicable gasifiers include: fixed bed, moving bed, entrained, Texaco type, Lurgi, and hydrodynamic. Models include oxygen reactions, steam, methanation, etc.

VALIDATION:

The models have not been tested with experimental data.

AVAILABILITY:

The models are available from the university.

REFERENCES: 15

THE BDM CORPORATION

6. TITLE: Modeling and Analysis of Moving Bed Coal Gasifiers

CONTACT: Linda F. Atherton

Electric Power Research Institute (EPRI)

3412 Hillview Ave., P.O. Box 10412

Palo Alto, Ca. 94303

Advanced Fossil Power Systems

(Project Manager - Liquefaction Research)

(415) 855-2526

DESCRIPTION:

A steady-state model of moving bed coal gasifiers has been developed based on kinetics and transport rate processes, thermodynamic relations, and mass and energy balances. Feasible operating regions for moving bed gasifiers have been analyzed and defined in terms of feed rates of fixed carbon, steam, and oxygen. Considerable insight into the sensitivity of the process to feed changes is obtained by thermodynamic equilibrium considerations. Rate process calculations with the model define the optimum feed ratios for a given coal and for a given mode of operations.

The model is further modified and applied to a pressurized slagging reactor.

The transient response of Lurgi and slagging reactors to small step changes from optimum feed conditions is studied by use of the above model together with a pseudo-steady state approximation. Predictions include the temperature and composition of the product gas as a function of time, the movement of the combustion zone in the Lurgi reactor, and the change in bed height in the slagging reactor.

A two dimensional model representation has recently been completed. This work was done by H. Yoon, J. Wei, and M. M. Denn of the University of Delaware.

THE BDM CORPORATION

VALIDATION:

Model predictions are in good agreement with published plant data for the Lurgi gasifier.

Results of the model applied to a pressurized slagging reactor are composed of data from a pilot scale experimental reactor, and reactor performance is examined over a range of operating conditions.

REFERENCES: 6, 10, 11, 12

THE BDM CORPORATION

7. TITLE: 1 DICO, PGC - 1

CONTACT: Phillip Smith
Brigham Young University
Provo Utah 84602
Dept. of Chem. Eng.
(801) 374-1211 X 4326

DESCRIPTION: Entrained flow gasifiers:

- (1) 1 DICO (1 dimensional combustion or gasification) employs a one dimensional variation in gas and particle distributions. The composition of gas and solids are the inputs and outputs. Plug flow is assumed.
- (2) PGC-1 (pulverized coal conversion or gasification) is being extended to a two dimensional model to handle turbulent flow (PGC-2). PGC-2 models general turbulent flow in 2 dimensions. It is intended to be operational by the end of the year.

VALIDATION:

- (1) The models are validated from local measurements of lab scale devices developed at BYU.
- (2) 1 DICO has been applied at Foster Wheeler and is now being sent to Babcock and Wilcox research facility at Alliance, Ohio (Jim Rice). There has been good agreement for "1-dimensional" reactors but poor agreement on turbulent reactors.

AVAILABILITY: The system is available with complete documentation.

REFERENCES: 5

THE BDM CORPORATION

8. TITLE: Complex Chemical Equilibrium Model

CONTACT: D. Kramer

NASA Marshall Space Flight Center

Huntsville, Alabama

DESCRIPTION:

The knowledge of chemical equilibrium compositions of a chemical system permits one to calculate theoretical thermodynamic properties for the system. These properties can be applied to a wide variety of problems in chemistry and chemical engineering. Some applications are the design and analysis of equipment such as compressors, turbines, nozzles, engines, shock tubes, heat exchangers, and chemical processing equipment.

Considerable numerical calculations are necessary to obtain equilibrium compositions for complex chemical systems. This has resulted in a computer program written at NASA Lewis Research Center in 1961-1962, with modifications added in 1971, the program is now capable of doing the following kinds of problems:

- (1) Obtaining equilibrium compositions for assigned thermodynamic states. The thermodynamic states may be specified by the assigning of two thermodynamic state functions (code names used in the program are given in parenthesis):
 - (a) Temperature and pressure (TP)
 - (b) Enthalpy and pressure (HP)
 - (c) Entropy and pressure (SP)
 - (d) Temperature and volume or density (TV)
 - (e) Internal energy and volume or density (SV)
 - (f) Entropy and volume or density

THE BDM CORPORATION

- (2) Theoretical rocket performance
- (3) Chapman-Jouget detonations
- (4) Shock tube parameter calculations

DOCUMENTATION:

The code and theoretical equations are documented in "Computer Program for Calculation of Complex Chemical Equilibrium Model Compositions, Rocket Performance, Incident and Reflected Shocks, and Chapman-Jouguet Detonations, Sanford Gordon and Bonnie J. McBride, NASA SP-273, 1971."

VALIDATION:

Informal comparison of results against limited data from commercial scale gasification plants show favorable results.

THE BDM CORPORATION

PART III
COST ESTIMATIONS AND FINANCIAL ANALYSIS

THE BDM CORPORATION

1. TITLE: COST

CONTACT: Fred Kessler
ICARUS Corporation
11300 Rockville Pike
Rockville, MD 20852
(301) 881-9350

DESCRIPTION:

COST is a system of computer programs developed for use by engineers and estimators in preparing capital investment estimates for process facilities. It provides total plan construction costs and schedules or it may be limited to costing plant sections, unit operations, or individual equipment items. To do this, the system calculates the purchase price for each item by utilizing design and costing models that simulate vendor design, fabrication, and pricing procedures. In like manner, COST simulates the material quantity take-offs a contractor would employ to generate field material and field labor installation of each equipment item. Appropriate engineering, overheads, contingencies, and fees are also calculated by the System.

The result of this estimating approach is a computer print-out with complete visibility and extensive details that reinforce every element of the estimate. COST printouts display the purchase prices for equipment, the installation labor and material costs, and a bill of materials for each equipment item. These data are also accumulated and displayed by unit operation and for the total facility.

COST is used to prepare estimates for many types of facilities such as:

- (1) Refineries
- (2) Coal Gasification/Liquefaction/Direct Conversion

THE BDM CORPORATION

- (3) Petrochemical
- (4) Power Plants
- (5) LNG
- (6) Chemical
- (7) Pulp and Paper
- (8) Metals and Ore Processing
- (9) Pharmaceutical
- (10) Waste Water Treatment

This capability includes grass roots facilities, expansions to existing plants, and revamps.

The system is used by:

- o Contractors:
 - To prepare preliminary, detailed, and control estimates.
 - To optimize equipment selection.
 - To evaluate process areas with high-dollar risk.
 - To aid sales efforts.
- o Owner/Operators
 - To determine project feasibility and prepare budgets.
 - To compare alternative processes or process sections.
 - To verify other estimates or bids.
- o Federal Government
 - To corroborate contractor bids.
 - To determine project feasibility and prepare budgets.
 - To evaluate scale-up to commercial operations.
 - To predict impact of future construction on job market and material production.

Icarus claims that estimates are accurate to within +15% to -0% of actual field construction costs.

THE BDM CORPORATION

Full plant estimates can be developed within days, as contracted with a month or more by hand.

The realism of the COST data base is maintained by semi-annual updating of the data base for 38 labor categories, thousands of material accounts, and over 300 equipment types.

COST does not employ inflation escalators; however these can be applied to the COST outputs in a straightforward manner.

COST is used in the conceptual design phase by providing the cost system as much information as the designer has available, and using system defaults for the costing. This has the advantage over traditional conceptual design costing methods vs factors are used: every piece of equipment, as well as bulk materials and labor are specified and costed directly.

Icarus will providing training for up to seven people in a four-day session for \$3800. Icarus will not permit government agencies to have direct access to the system, but only through Icarus consulting or through contractors. As with all other computer systems, an experienced and knowledgeable user is required to obtain meaningful results.

DOCUMENTATION:

A complete set of manuals can be purchased from Icarus for \$200.

AVAILABILITY:

COST is available through direct timesharing use or through Icarus consulting support. Icarus does not allow direct timesharing use by government agencies, but only through Icarus consulting support or through other government contractors.

THE BDM CORPORATION

2. TITLE: Chemical Engineering Economic Package (CHEEP)

CONTACT: R. L. Motard

or

F. L. Worley, Jr.

Dept. of Chem. Eng.

U. of Houston

Houston, TX 77004

DESCRIPTION:

Program accepts a description of a chemical plant and produces a preliminary sizing and cost estimate of the equipment in the plant. A summary of installed and operating costs is also computed, and a profitability is generated. The system may be integrated with CHESS or run in stand-alone mode. Equipment estimation includes distillation and absorption columns, heat exchangers (single phase, condensers, kettle/reboilers), reactors (batch, continuous stirred-tank, tubular), furnaces, pumps, compressors and tanks.

THE BDM CORPORATION

3. TITLE: Economist

CONTACT: Dr. P. Winter
Head of Chem. Eng. Group
Computer Aided Design Centre
Madingley Road
Cambridge CB3 0HB
United Kingdom
or
Dr. Mike E. Leesley
The Concept Group
Chem. Eng. Dept.
U. of Texas
Austin, TX 78712

DESCRIPTION:

A suite of programs for capital cost estimation and project evaluation. The program is run in two parts as follows: ECONOMIST I, Capital Cost Estimation, consists of a library of routines, each of which contains sets of cost functions and factors for estimating the capital cost of related types of equipment. The total plant cost is estimated from the overall equipment cost by means of modified Lang factors. ECONOMIST II, Operating and Manufacturing Cost and Project Evaluation, uses cost correlations and factors to estimate operating and manufacturing costs of chemical plant. Variable parts of operating costs, together with fixed and semivariable costs, are calculated. Interactive facilities enable the engineer to specify the type of depreciation labor requirements, and so on. The implications of alternative courses of action can be examined, and a record is kept of all transactions. A number of well known economic appraisal techniques are available for carrying out project evaluation. Present size restriction of 70 units may be altered on request to suit the user.

THE BDM CORPORATION

4. TITLE: Guthrie Modular Approach (Manual Technique)

CONTACT: K M. Guthrie

Process Plant Estimating, Evaluation and Control
Craftsman Book Company of American (now by McGraw-
Hill, N.Y.)

Solana Beach, CA, 1974, 604 pp.

DESCRIPTION:

Based on cost patterns and relationships from more than 50 refineries and processing plants, this book identifies individual types of equipment by size, duty, construction materials, etc. The purchased equipment cost (E) will have a prescribed percentage of field materials (M) added. These include piping, concrete, structural steel, electrical, instrumentation, insulation and painting. The total material costs are flexible depending upon special size or process conditions which affect type of material and field or ship fabrication. The labor component (L) for erection of equipment and installation of field materials is added to derive the direct cost (E+M+L).

Project Indirect Costs, comprised of construction overheads, home office and engineering expenses are added to derive a modular cost. If specifically warranted, a particular equipment item may have a process contingency applied before obtaining the modular item cost. The sum of all of the modular item costs has a project contingency applied to result in installed plant investment. The method does not extend beyond this point but the Project Total Capital Requirement will include any Allowance for Funds Used During Construction, Start-up and Organization Expenses, Initial Charges of Catalyst and Chemicals, and appropriate Working Capital amounts.

The most apparent inconvenience when using Guthrie's method is the necessity to update costs and cost-relationships from his

THE BDM CORPORATION

Mid-1970 datum price level to the desired date. This would be accomplished most effectively by use of the W. L. Nelson Equipment Price Indices, published quarterly in the Oil and Gas Journal, for each type of equipment, or more expediently through use of the Marshall and Stevens (M&S) chemical process plant index in the Chemical Engineering Magazine.

THE BDM CORPORATION

5. TITLE: Heat Exchanger Pricing Program

CONTACT: Irven H. Rinard
Director of Process Applications
Halcon Computer Technologies, Inc.
Two Park Avenue
New York, NY 10016

DESCRIPTION:

Will price the following types of tubular heat exchangers: (1) single or multipass fixed tubesheet; (2) internal floating head; (3) U-tube bundle and shell; (4) kettle with U-tube bundle; (5) U-tube bundle only. Two types of input are possible, depending on amount of information available. If only surface area is known, program will size heat exchanger and estimate thicknesses. Alternatively, if a detailed physical description of a heat exchanger is known, the program will utilize these facts. The estimate is based on actual fabrication of the exchanger for a wide variety of materials. Five cost-indexes are included, which the user can vary if he desires. The output provides costs, weights, fabrication manhours, and the amount of external surface to be painted or insulated.

THE BDM CORPORATION

6. TITLE: PCOST

CONTACT: G. V. Reklaitis, Assoc. Prof.
Purdue University
Dept. of Chem. Eng.
West Lafayette, IN 47907

DESCRIPTION:

A program package for equipment cost estimation and project economic evaluation. The package contains an extensive data base of equipment-cost correlating functions, an efficient data-base management system, a library of routines for equipment-cost estimation, and programs for total plant-cost estimation. Total plant cost is based on a detailed estimate of utility and other off-site expenses and a factored estimate of major process equipment installation and other costs. An optional economic-evaluation calculation based on a discounted-cash-flow analysis can also be made using an adaptation of the Oak Ridge National Laboratory program PRF. The user has the option of selecting specific cost correlations or of obtaining a range of cost estimates based on all available correlations for a given equipment item. Required user input consists primarily of equipment specifications, with the level of detail depending upon the level of estimate required. The user may enter actual quoted costs for any item, supply special multipliers for f.o.b. cost, installation labor and materials, and select any particular cost escalation index. Flexible report-generating options are provided, including detailed plant-section-wise or equipment-class-wise summaries.

THE BDM CORPORATION

7. TITLE: PEPCOST - Computer Program to Estimate Capital and Production Costs

CONTACT: Mrs. Janet E. Dinger
Stanford Research Institute
Menlo Park, CA 94025

DESCRIPTION:

The PEPCOST program is used to estimate and print out: equipment costs, from specifications supplied by the user; battery limits and utilities investment; production costs. In addition, printouts are made of the following: major equipment list; utilities summary; echo of input data. PEPCOST contains routines for estimating the cost of the following equipment: pressure vessels; columns, trays, and packings; shell-and-tube exchangers; compressors; pumps; tanks (storage of process); direct furnaces.

THE BDM CORPORATION

8. TITLE: Preliminary Economics Computer Program (E-301 Program)

CONTACT: Irven H. Rinard
Director of Process Applications
Halcon Computer Technologies, Inc.
Two Park Ave.
New York, NY 10016

DESCRIPTION:

A FORTRAN IV-G level language computer program has been developed to prepare preliminary estimates of capital cost and the economics for any process for which sufficient data exist. It gives the battery limits capital cost and transfer price of the chemical at the desired production rate. The printout of four pages includes the elements of production cost both on a priced-out and an unpriced basis, a breakdown of the capital cost with appropriate cost escalation, and notes relating to the particular process. A permanent set of data is stored in the computer operations area for each process and has an identification number. Each set, along with the data of the particular case supplied by the engineer user, is used to produce the estimate. The program may also be used to prepare a priced-out estimate of transfer price if a battery-limits capital cost is known from another source. The program input form has been designed such that if standard raw-material, labor, and utility costs are used, only the capacity need be provided as basic input. The program is quite versatile since it permits output in both metric and U.S. or English units, converts monetary units to a variety of currencies, permits adjustments of costs to reflect local and extent conditions, and has standard local utility costs available to it for a number of countries. The output is in suitable form for photocopying directly on a Multilith master for reproduction.

THE BDM CORPORATION

9. TITLE: Pressure Vessel Cost Estimating

CONTACT: Irven H. Rinard
Director of Process Applications
Halcon Computer Technologies, Inc.
Two Park Ave.
New York, NY 10016

DESCRIPTION:

Program offers the cost engineer a rapid and systematic approach in estimating vessel costs. A basic set of design and cost data have been built into the program so that required input is kept to a minimum. Flexibility is enhanced by various options through which a user may override the built-in values. The program accepts input from process sketches and preliminary drawing for cost estimating purposes. It computes head thickness and shell thickness for predetermined course lengths of a vessel subject to pressure, wind and earthquake loadings. Pricing is based on cost estimating data of December, 1967. The output information includes vessel shell, skirt and head thickness, design data, material cost, fabrication cost, shop burden, tray and tray installation cost and profit. The weights of the major components of the vessel are printed and summarized. In addition, the volume and the surface area of the vessel are also given.

THE BDM CORPORATION

10. TITLE: Price and Delivery Quoting Service for Chemical Process Equipment (PDQ\$)

CONTACT: Gustav Enyedy, Jr., Pres.

PDQ\$, Inc.

Route 1, Box 64

Gates Mills, OH 44040

DESCRIPTION:

Provides current equipment costs inexpensively in a matter of minutes through a telephone-connected computer terminal, eliminating the need to search through manuals and the trade literature for historically based data, or to get a vendor quote. A PDQ\$ Inquiry is processed in seconds and matched to the amount of detail that is supplied. This service is particularly useful at the conceptual stage. A minimal amount of input data results in a preliminary design for fabricated equipment and a tentative selection for catalog items. The costs quoted from the selections are actual vendor prices for existent sizes of the specified equipment. Thus, the preparation of total plant-cost estimates can start with current, non-factored, non-indexed equipment costs as a base, greatly increasing the probable accuracy of the final result.

THE BDM CORPORATION

11. TITLE: Project Valuation and Estimation System (PROVES)

CONTACT: Gustav Enyedy, Jr.
Engineering Consultant
Route 1, Box 64
Gates Mills, OH 44040

DESCRIPTION:

Designed to evaluate projects, using limited data. If input information is unknown or incomplete, program will supply average values to approximate decision parameters and to point out suspect data. PROVES is also useful in selecting the most profitable process from alternative ones. Program is composed of four major parts that can be entered and exited at any step: (1) MODEL (Material and Operation Design Elaborator) - Every process can be described with only four basic operations (mixing, splitting, separation, reaction). Thus, MODEL completes a material balance in less time than more elaborate programs, and with a small computer. (2) SCOPE (Sizing and Costing of Process Equipment) - This estimates costs of major pieces of equipment and their utilities requirements. It contains PROPS, a program that makes a preliminary pass at the data to determine what physical properties are necessary. (3) INVEST (Investment Estimator) - This part estimates cost of total plant investment. (4) EFFECT (Economic Feasibility Using Forecasting, Estimating and Cashflow Techniques) - This estimates manufacturing cost, profitability parameters, and does a sensitivity analysis.

THE BDM CORPORATION

12. TITLE: Richardson Rapid System

CONTACT: Richardson Engineering Services, Inc. - THE RICHARDSON RAPID SYSTEM - PROCESS PLANT CONSTRUCTION ESTIMATING STANDARDS, 4 Volumes, published annually with quarterly construction Cost Trend Reporter updating, Solana Beach, California.

DESCRIPTION:

The build-up of total capital requirements follows the same general approach as Guthrie's Modules with more detailed specificity of sub-accounts. The data presented within the books are correct and quite detailed with indices and wage rates for specific geographic locations. The estimates may vary from preliminary conceptual feasibility studies through competitive firm price bidding and evaluation of change orders. In Volume 4, Process Equipment, each particular type of common process device is defined and costs specified. The construction costs estimated by this method will require the addition of contractor's fee or profit, any relevant project contingency factors and working capital to yield total capital requirements. A form of process contingency can be included within the equipment costs through consideration of special job conditions.

The virtues of Richardson's method are numerous, with current prices by location and detailed listings of equipment and construction labor crafts and manpower requirements. The drawbacks may be that conceptual plant designs must be quite detailed to assure inclusion of all items by size and function, and that estimating the total facilities costs for a conceptual plan would require more estimating time.

THE BDM CORPORATION

13. TITLE: Shell and Tube Heat Exchange Cost Estimation, Program 5066 (Phillips Petroleum Co. Program Package 1)

CONTACT: William R. Vickroy
V.P., Marketing
McDonnell-Douglas Automation Co.
St. Louis, MO 63166

DESCRIPTION:

Estimates cost of a shell-and-tube heat exchanger by summing the cost of the individual component costs. User may specify almost any standard shell-and-tube arrangement. Required input data have been kept to a minimum by having tables of cost, materials, etc., stored internally. An estimate based on current material costs may be obtained by using cost index factors to update the cost data stored in the tables. Phillips compared estimated and purchase cost of 49 exchangers. Results were that estimated cost should lie between ± 0.45 and 20% of actual cost.

THE BDM CORPORATION

14. TITLE: Wastewater Treatment Plant Cost Estimating

CONTACT: Mr. Richard G. Ellers
Mathematical Statistician
Environmental Protection Agency
National Environmental Research Center
Advanced Waste Treatment Research Laboratory
Treatment Optimization Research Program
Cincinnati, OH 45268

DESCRIPTION:

This program computes the capital, amortization, operation-and-maintenance and total treatment costs associated with building and operating wastewater treatment plans. Both conventional and tertiary treatment processes can be included. The program calculates and prints out the costs for each process and sums the costs for the entire system. The user need only supply various design parameters as input. It is possible to input an amortization factor, construction cost index, and hourly wage rates.

THE BDM CORPORATION

ECONOMIC AND FINANCIAL EVALUATION

B-71

THE BDM CORPORATION

1. TITLE: A Review of Cost Estimation in New Technologies: Implications for Energy Process Plants

CONTACT: E. H. Merrow,
Rand Corporation
Santa Monica, California, 90406

DESCRIPTION:

This report reviews literature on cost estimation in several areas involving major capital expenditure programs: energy process plants, major weapons systems acquisition, public works and large construction projects, and cost estimating techniques and problems for chemical process plants. Specifically, the study of which this review is a part addresses the following questions:

- What has been industry's estimating and performance experience with first-of-a-kind plants?
- What factors have been associated with different levels of cost growth and performance shortfall?
- What are the implications of industry's experience for the ways in which the Department of Energy plans and manages the development and commercialization of new energy process plant technologies?

One of the goals of this review was to aid in the development of a conceptual framework for the study. That framework will be incorporated into subsequent reports.

THE BDM CORPORATION

2. TITLE: CASHFLOW

CONTACT: Dale W. Kirmse
Chem. Eng. Dept.
U. of Florida
Gainesville, FL 32611

DESCRIPTION:

Life Cycle Cost Analysis - Calculates cash flows and provides life-cycle cost analysis for energy systems. A name-list input is used to input values for usage and costs of energy resources as well as the life-cycle capital costs estimates and assumed escalation rates of usage and costs of each energy source, incremental cash flows, and evaluate profitability measures.

THE BDM CORPORATION

3. TITLE: Cash Flow Analysis (CFA)

CONTACT: Ivan W. Klumper
Group Leader
Kennecott Copper Corp.
128 Spring St.
Lexington, MA 02173

DESCRIPTION:

Calculates net present value and DCF rate-of-return of complex ventures. It also computes annual depreciations, depletion allowances, taxes, profits and cash flows based on multiple investment outlays and year-by-year variations in plant capacity, sales volume, selling price, working capital, operating cost, R&D expense and other corporate charges. Different depreciation schedules may be used for each investment outlay. Working capital and operating cost are estimated from fixed capital, raw materials, utilities and labor costs using standard factors.

THE BDM CORPORATION

4. TITLE: Cash Flow Forecast

CONTACT: Phillip C. Quo
A.M. Kinney, Inc.
Consulting Engineers
2900 Vernon Place
Cincinnati, OH 45219

DESCRIPTION:

Estimates, for a project, the net cash available to equity in each year for the lifetime of the project. The program will also compute the discounted rate of return. It is designed to accept four methods of depreciation: double decline, straight line, sum-of-years-digits and decline balance. The input consists of unit selling prices and total sales for three cases, tax rate, annual raw material cost, annual operating cost, annual production transportation cost, project life, total depreciation, total debt payments, total working capital, debt portion of working capital, interest rate, salvage value and depreciation period. The output contains a tabulation of information for 20 years including the inputs and the following: total cost, profit before and after tax, debt payments for plant and working capital, and net cash available to equity in each period.

THE BDM CORPORATION

5 TITLE: Chemical Process Screening Program

CONTACT: Dr. Herbert T. Bates
 Kansas State U.
 Dept. of Chem. Eng.
 Manhattan, KS 66502

DESCRIPTION:

Used to make a preliminary economic analysis of a chemical process enterprise. It produces a raw-material-economics sheet and a profit-and-loss statement for a mature year. The input information is documented in the comments at the top of the program.

THE BDM CORPORATION

6 TITLE: Discounted Cash Flow Calculations

CONTACT: D. M. Marsland
 Dept. of Chem. Eng.
 N.C. State U.
 P.O. Box 5035
 Raleigh, NC 27607

DESCRIPTION:

Periodic cash flows are developed from vectors in the argument list, and the cumulative discounted cash flow is formed, based on end-of-period accounting and discrete compounding. Two kinds of output, full and summary, are generated by an associated output subroutine.

THE BDM CORPORATION

7 TITLE: Discounted Rate of Return on Investment

CONTACT: Phillip C. Quo
A.M. Kinney, Inc.
Consulting Engineers
2900 Vernon Place
Cincinnati, OH 45219

DESCRIPTION:

Designed to compute the discounted rate of return on investment. The discounted rate of return is based on average continuous rate of compound interest that is earned by a project on the money invested in that project over the life assignable to it. The program will also calculate the zero interest break-even point and a cumulative cash flow during end of each period. The program can either be run independently of or linked to "cash flow forecast program" (Program 280, directly above). When run independently, the input to the program consists of unit gas cost, unit selling price, depreciation, project life, and cash flows in each year. No input is needed when the program is linked to "cash flow forecast." The output contains undiscounted cash flow, discounted cash flow and cumulative cash flow at the end of each period, zero interest break-even point, and discounted rate of return in percentage.

THE BDM CORPORATION

- 8 TITLE: Economic Evaluation of Municipal Water Supply and Waste Water Disposal Including Considerations of Seawater Distillation and Wastewater Renovation

CONTACT: Mr. Richard G. Ellers
Mathematical Statistician
Environmental Protection Agency
National Environmental Research Center
Advanced Waste Treatment Research Laboratory
Treatment Optimization Research Program
Cincinnati, OH 45268

DESCRIPTION:

Can be used in determining the least-cost alternative for meeting major water demand and wastewater disposal requirements within a metropolitan area. The mathematical model comprises three basic components: (1) the preprocessing program, (2) the network program, and (3) the recosting program. The network program is based on integer linear programming and uses the "out-of-kilter" algorithm. The preprocessing program is used to calculate unit costs for each area of the network. The recosting program is used to correct for the fact that costs are not linear with size.

THE BDM CORPORATION

- 9 TITLE: Economic Evaluation of Process Operating and Capital Costs

CONTACT: Leonard Silver
 Mgr., Automation & Control Development
 Merck & Co.
 126 East Lincoln Ave.
 Rahway, NJ 07065

DESCRIPTION:

A computer-aided system for the estimation of chemical process costs has been extended to include both the estimation of capital costs and a more accurate calculation of production costs. The economics of relatively complex processes can be predicted from either lab or pilot-plant data. Cash flows for venture analysis can be readily estimated as a function of processing method and/or production rate at various stages of process development.

THE BDM CORPORATION

- 10 TITLE: Guidelines for Economic Evaluation of Coal Conversion Processes

CONTACT: B. C. McBeath

The Engineering Societies Commission on Energy, Inc.
444 North Capitol Street, N.W., Suite 405
Washington, D.C. 20001

DESCRIPTION:

These guidelines were developed for use in preparing and reporting engineering designs, cost estimates and financial analyses of large-scale fossil energy facilities. They provide a uniform basis for presenting project expectations so that comparison between alternative projects can be done on a consistent basis by the U.S. Department of Energy and thereby assist in the establishment of technical development priorities.

The guidelines are primarily for the preliminary economic analysis of coal conversion projects, producing either gas or coal liquids. In a preliminary estimate, the process, equipment and site factors are sufficiently defined to justify a preliminary engineering design. However, the general structure and subject matter of these guidelines are applicable to either more simplified or more detailed analyses of energy facilities.

The guidelines are organized by types of information needed in evaluating the economics of a project. Documentation of specific items relating to project scope, process design, capital and operating cost estimates and financial analyses is required to aid in assessing and interpreting reported results. Particular emphasis is placed on the treatment of capital cost estimates of new processes at various stages of technical development. Also, the financial methods and parameters to be used in determining the required selling price of products are defined in order to establish a base case for sensitivity analysis of

THE BDM CORPORATION

technical, locational or financial variables. In addition, an appraisal of the results is requested of those responsible for preparing the project evaluation report.

THE BDM CORPORATION

11 TITLE: Planning and Analysis in Uncertain Situations (PAUS)

CONTACT: Monte G. Smith, Pres.
Bonner & Moore Software Systems
Suite 1124
500 Jefferson Bldg
Houston, TX 77002

DESCRIPTION:

This is a tool for the analysis of decisions related to investments, marketing strategies, cost estimates, bidding, or any other decision area in which uncertainty may play a major role. The package is often used to assess the risks involved in ventures such as the building and operation of a refinery or petrochemical plant. It is a general-purpose system that uses Monte Carlo techniques to allow a user to include uncertainty estimates surrounding each decision factor. The system provides built-in probability distributions, correlation capability, and user-oriented language. Output is user controlled and presents the decision maker with statements concerning risks involved in a decision. Built-in case-study mechanisms facilitate sensitivity analysis. DCF and ROI computations are also built into the system.

THE BDM CORPORATION

12. TITLE: PRF - A Discounted Cash Flow Program for Calculating the Production Cost of the Product from a Process Plant

CONTACT: Royes Salmon
Oak Ridge National Laboratory
Oak Ridge, TN 37830

DESCRIPTION:

Calculates the cost of the product from a process facility, when the capital investment, operating costs, interest rates, tax rates, byproduct values, and similar related information are supplied by the user. The program uses a procedure that is mathematically consistent with the discounted-cash-flow method, and produces a table showing the cash-flow history of the project. Flexibility is afforded in the choice of capital structure, depreciation method, and the handling of taxes. Provision is made for parametric studies in which the cost of the feedstock and the annual after-tax rate-of-return on equity are varied automatically over any desired stage. The program can also be used to determine the rate of return on equity when the selling price of the product is supplied by the user.

THE BDM CORPORATION

13. TITLE: Profitability Estimation Using Probabilistic Data Inputs

CONTACT: Albert J. Berger
Chem. Eng. Curriculum
Rensselaer Polytechnic Institute
Troy, NY 12181

DESCRIPTION:

As after tax rate-of-return economic evaluation is performed using a Monte Carlo simulation procedure. Probabilistic inputs include: primary raw-material cost, primary product sales-price, and initial fixed capital investment. These probabilistic inputs are independent normally distributed random variable having a specified mean and standard deviation. The computer program iteratively calculates a rate-of-return described by a frequency distribution, a probability of occurrence function, a cumulative probability function, as well as a mean and a standard deviation.

THE BDM CORPORATION

14 TITLE: PROFIT (Interactive)

CONTACT: Bruce A. Finlayson
Associate Professor
Dept. of Chem. Eng.
U. of Washington
Seattle, WA 98195

DESCRIPTION:

Analyzes investments using four methods: discounted cash flow, present worth, capitalized cost, pay-out period (including interest). Depreciation is figured using one of three methods: straight line, declining balance, sum of years digits. Interest can be figured as either discrete or continuous and a tax rate can be included. The program operates in an interactive mode. The user calls the program and answers the questions the computer asks. The user must specify the time interval considered, the fixed capital investment for each year, working capital, use of equipment, the year the equipment can begin to be used, salvage value, replacement value, revenue for each year, and cash expenses for each year. The yearly information can be submitted year by year, or fit by a linear equation.

THE BDM CORPORATION

REFERENCES

B-87

THE BDM CORPORATION

REFERENCES

1. "A Prospectus for Participation in the Industrial Testing of ASPEN," M.I.T., Energy Laboratory (July, 1979).
2. "Computer - Aided Industrial Process Design - The ASPEN Project," M.I.T., Dept. of Chem. Eng. and Energy Laboratory, THIRD ANNUAL REPORT FOR THE PERIOD June 1, 1978 to May 31, 1979 (June 15, 1979).
3. "Computer - Aided Industrial Process Design - The ASPEN Project," M.I.T., Dept. of Chem. Eng. and Energy Laboratory, ELEVENTH QUARTERLY PROGRESS REPORT FOR THE PERIOD December 1, 1978 to February 28, 1979 (March 15, 1979).
4. "Materials - Process - Product Analysis of Coal Process Technology," Final Report for Project Phase II, International Research and Technology Corporation, McLean, Virginia, Vol's I-III (September, 1978).
5. Abstract from Brigham Young University.
6. "Modeling and Analysis of Moving Bed Coal Gasifiers", H. Yoon, J. Wei and M. Denn, U. of Del., Dept. of Chem. Eng., Vol. 1 (November, 1977), Vol. 2 (February 1978).
7. "Support Research on Chemical, Mechanical, and Environmental Factors in Underground Coal Gasification," T.F. Edgar, M.J. Efumenick, T.W. Thompson, and K.E. Gray, U. of Texas at Austin, Dept. of Chem. Eng., QUARTERLY REPORT (July 1, 1979).
8. "A Review of Cost Estimation in New Technologies, Implications for Energy Process Plants", Merrow, E.W., Chapel, S.W.; and Worthing, C.; the RAND Corporation, R-2481-DOE (July, 1979).
9. "Guidelines for Economic Evaluation of Coal Conversion Processes", McBeutle, B.C., the Engineering Societies Commission on Energy, Inc., Washington, D.C. (April 1979).
10. "A Model for Moving-Bed Coal Gasification Reactors," H. Yoon, J. Wei, and M. M. Denn, AIChE Journal, Vol. 24, No. 5 (September, 1978), p. 885.
11. "Feasible Operating Regions for Moving Bed Coal Gasification Reactors," H. Yoon, J. Wei, and M. M. Denn, I&EC PROCESS DESIGN & DEVELOPMENT, Vol. 18 (April, 1979), p. 306.
12. "Transient Behavior of Moving-Bed Coal Gasification Reactors," H. Yoon, J. Wei, and M. M. Denn, AIChE Journal, Vol. 25, No. 3 (May, 1979), p. 429.

THE BDM CORPORATION

13. "Fluidized Bed Gasification Reactor Modeling. 1. Model Description and Numerical Results for a Single Bed," H. S. Caram and N. R. Amundson, I&EC PROCESS DESIGN & DEVELOPMENT, Vol. 18 (January, 1979), p. 80.
14. "Fluidized Bed Gasification Reactor Modeling. 2. Effect of the Residence Time Distribution and Mixing of the Particles, Staged Beds Modeling," H. S. Caram and N. R. Amundson, I&EC PROCESS DESIGN & DEVELOPMENT, Vol. 18 (January, 1979), p. 96.
15. "Simulation of Fluidized Bed Coal Combustors," P. Rengarajan, R. Krishan, and C. Y. Win, NASA CR-159529 (February, 1979).
16. "DSS/2 (Differential Systems Simulator, Version 2), Dynamic Gasifier Model," H. S. Caram and B. Patrose, Lehigh University (January 15, 1979).
17. "Modeling of Coal Conversion Technologies," R. W. Roig, International Research and Technology Corporation, McLean, Virginia, THE INSTITUTE OF MANAGEMENT SCIENCES XXIV INTERNATIONAL MEETING, HONOLULU, HAWAII (June, 1979).